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The western yellow pine mistletoe - Its effect on growth and suggestions for its control. Kenneth Long

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Its Effect on Growth and Suggestions for its Control

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THE WESTERN YELLOW PINE MISTLETOE:

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[1]The discussion of "The Western Yellow Pine Mistletoe", pp. 8-9, "Hypertrophy and Resin Flow", pp. 24-27, and "Effect on Foliage", pp. 27-29, is largely the work of Dr. Long. In the main this bulletin presents the results of field work conducted under the supervision of the authors; Dr. Long being responsible for the strictly pathological material and Mr. Korstian for the remainder, i.e., the growth data, material on silvicultural aspects and control. The writers are indebted to Silviculturist G. A. Pearson, of the Fort Valley Experiment Station for the permanent sample plot data contained in Tables 11 and 17, for the data on the 1915 seed collection contained in Table 18, and for his general interest shown during the progress of the investigation.

INTRODUCTION

During the past ten years studies have been in progress, the object of which was to determine the effect of the western yellow pine mistletoe (Razoumfskya cryptopoda (Engelm.) Cov.) on the growth and seed production of western yellow pine (Pinus ponderosa Laws.) Western yellow pine occurs naturally from southern British Columbia to northern Mexico and from the Pacific Coast to east of the one-hundredth meridian. It is found in the forests of every state west of the Great Plains and in over half of them it is the most important and valuable forest tree. In the Southwest western yellow pine is by far the most important timber tree, comprising over 80 per cent of the commercial forests of Arizona and New Mexico or approximately 17 billion board feet.

The western yellow pine mistletoe is very widely distributed in the western yellow pine forests of the Southwest and occurs in such abundance in many localities as to assume a very serious aspect in relation to many forest problems. In widely scattered localities in the western yellow pine type especially on southern exposures and near the lower limit of the type, areas may be found on which fully 75 to 90% of all the trees

above 6 inches in diameter are infected with mistletoe. In fact the mistletoe is the most widely distributed and one of the most serious diseases of the western yellow pine, and this pest has confronted the forester from the beginning of silvicultural practice in the Southwest. In marking western yellow pine, the question is often raised as to the advisability of cutting trees of various ages and degrees of mistletoe infection or of allowing them to remain as seed trees and form a part of the future stand which will provide the basis for a subsequent cut. The solution of this problem involves not only a study of the effect of mistletoe on the rate of growth and the longevity of its host but also the effect of the parasitism on the amount and periodicity of seed production.

PHYSICAL AND CLIMATIC FEATURES OF THE REGION.

The localities in which the intensive studies were conducted lie within the Coconino and Tusayan National Forests on the Colorado Plateau, near the San Francisco Mountains in northern Arizona. The general topography of the plateau is rolling and consists of alternating flats comparatively free from rock and of rather low ridges which are very rocky. The underlying rock of the Plateau consists principally of Coconino sandstone and Kaibab limestone overlain by a lava flow of basalt

and acidic volcanic rocks, mainly dacite, andesite, rhyolite and latite, which comprise the main outcrops and surface rocks of the region. The soil varies widely from a fine sandy loam to a reddish friable clay, often containing an admixture of gravel and large volcanic boulders. In a greater part of the region northeast of the San Francisco Mountains the soil is covered with black volcanic cinders to depths varying from 1/2 to about 18 inches. Mistletoe infection is rare on these cinder areas and where found at all is light. The level mesas and lower slopes of the Plateau ranging from approximately 6,500 to 8,500 feet in elevation are covered with a forest of which approximately 95 per cent is western yellow pine, comprising the most extensive forest of this species in North America.

The climate of that portion of the Colorado Plateau which is covered with a western yellow pine forest may be exemplified by the climatological data which have been secured at the Fort Valley Forest Experiment Station. Pearson's[2] studies in this locality, together with the records of the U. S. Weather Bureau throughout the region have shown that the climate is characterized by marked seasonal variations in precipitation, atmospheric humidity

2. Pearson, G. A. A meteorological study of parks and timbered areas in the western yellow pine forests of Arizona and New Mexico. Monthly Weather Review 41: 1615-1629, 1914.

and wind movement, and great daily ranges of atmospheric temperature. The amount of sunshine is unusually high. The mean annual precipitation in the western yellow pine forest amounts to between 20 to 25 inches which occurs in two well-defined periods, during July and August in the form of thunder showers, and from November to April in the form of snow. The intervening period from about April 15 to July 15, is characterized by desiccating southwest winds and excessive evaporation which, together with the small amount of precipitation, produce conditions adverse to most types of vegetation. The high rate of evaporation, low atmospheric humidity and high wind velocity very often cause excessive transpiration from plants. The climatic and soil conditions are such that nowhere within the western yellow pine type of the Southwest does this species make rapid growth.

The influence of such climatological conditions is generally considered unfavorable to the best development of the host and favorable to the growth of the parasitic mistletoe. Weir[3] has emphasized the fact that the ecological relationships of the mistletoes, although they are parasitic, are similar to those of other chlorophyllaceous plants in that they also respond to light, gravity,

[3] Weir, James R. The larch mistletoe: some economic considerations of its injurious effects. U. S. Dept. of Agri. Bul. 317, pp. 5-10, 1916.

and certain chemical stimuli, while the marked variations in temperature to which the host readily responds are only slightly effective on the parasite. The low atmospheric humidity has a very slight influence on the xerophytic mistletoe, while the great amount of sunshine is favorable to the parasite. The unusually high winds of the Southwest frequently cause rather serious losses to western yellow pine stands in exposed situations through windfall while the wind is known to actually aid in the dissemination of the mistletoe seed from tree to tree. It is thus evident that the climate must exert a favorable influence on the distribution and growth of the parasitic mistletoe in the Southwest. It follows then that, where a virulent parasite responds favorably to its habitat, the host will rapidly deteriorate on the more unfavorable sites. From numerous observations made by the writers in various parts of the Southwest, it is apparent that a rather definite relation exists between the unfavorableness of the site and the degree of mistletoe infection. The percentage of infection and the resulting mortality of the host is usually higher on exposed dry ridges and south slopes than on the more favorable sites. This condition is very apparent on the Santa Fe National Forest in northern New Mexico.

THE WESTERN YELLOW PINE MISTLETOE

The family Loranthaceae has two genera in the United States, Phoradendron and Razoumofskya. The species of Phoradendron are parasitic on both hardwoods and conifers, but mainly on hardwoods, while the genus Razoumofskya is found exclusively on conifers. Several species of the latter genus are rather common in the Western United States and in some localities have become very serious parasites. Razoumofskya cryptopoda, the western yellow pine mistletoe, is one of the most widely distributed of all the species, usually being found wherever the western yellow pine grows.

Razoumofskya cryptopoda flowers in Arizona and New Mexico during April and May, and the fruit matures in August and September of the next year. When the seeds begin to ripen, the berries gradually turn downward on their pedicels until the base of each berry when fully mature points upward. The gelatinous seeds when ripe are suddenly and forcibly ejected upward to a distance of several yards by the fiving way of a ring of tissue situated near the base of the berry. This method of seed dissemination is common to all of

the species of Razoumofskya. Experiments conducted by the writers, as well as extended observations, indicate that the aerial portions of both staminate and pistillate plants die and fall from the trees after one season of flowering and fruiting.

EFFECT OF MISTLETOE ON GROWTH OF HOST

The study of the effect of mistletoe on its host was accomplished, (1) by periodic measurements and observation on standing trees, both infected and healthy; and (2) by detailed growth studies and observations of infected and healthy felled trees.

Effect on Bole of Tree:

Ninety-one healthy and mistletoe-infected trees between 10 and 30 inches in diameter breast high on three different areas within a radius of five miles of the Fort Valley Experiment Station were tagged, numbered, measured and mapped in 1910 with the object of determining the effect of mistletoe on the diameter and height growth of the host, the diameter growth of limbs, and the merchantable growth, i.e., the growth of the merchantable contents of the bole. The diameters

were measured with a diameter tape at 1, 4, 5, 17 and 33 feet above the ground. The total heights were measured with a Forest Service standard hypsometer. The diameters of 20 healthy and 34 mistletoe infected limbs falling in the different infection classes mentioned below were measured on 18 standing trees with a view of determining the effect of mistletoe on the growth of limbs. The points of measurement at 6 inches from the bole of the tree and every 6 inches beyond this point were marked by driving a 6d copper nail into the wood. All of the trees were remeasured in 1915 and were reclassified into four degrees of mistletoe infection according to the prevalence of mistletoe on the tree as follows: o - healthy trees without mistletoe, x - light mistletoe infection, xx- medium mistletoe infection, xxx - heavy mistletoe infection.

In order to check any material effect that the different crown classes might have on the rate of growth the trees were also classified, according to their dominance or relative position in the crown canopy of the group, into the following crown classes.

Isolated: Trees growing in the open which do not form a contiguous part of the regular group canopy.

Dominant: Trees with crowns extending above the general level of the group canopy and receiving full light from above and partly from the sides; larger than the average trees in the group, and with crowns well-developed but possibly somewhat crowded.

Codominant: Trees with crowns forming the general level of the group canopy and receiving full light from above but comparatively little from the sides; usually with medium-sized crowns more or less crowded on the sides.

Intermediate: Trees with crowns below, but still extending into the general level of the group canopy, receiving a little direct light from above but none from the sides, usually with small crowns considerably crowded on the sides.

Suppressed: Trees with crowns below the general level of the group canopy and receiving no direct light either from above or from the sides; usually with small, poorly developed crowns.

There are two well-recognized forms of Pinus ponderosa, "black jack" and "yellow pine", based on age, rate of growth, and the resulting color of the bark. The term "black jack" applies to the young, vigorous trees under 125 to 150 years old which are characterized by a dark, almost black, or dark brown, narrow-furrowed bark.

The "yellow pine" form comprises the older trees which are characterized by a yellowish or reddish brown, widely furrowed bark. There is a marked difference in the form and volume of black jacks and yellow pines. The average black jack has a greater taper, a more rapid rate of growth, and approximately 10 per cent smaller cubic volume than the average yellow pine of the same diameter and height, which were the chief reasons for the segregation of black jacks and yellow pines.

The mean diameter growth or accretion of the standing black jacks for the 5-year period from 1910 to 1915 grouped according to degree of mistletoe infection is shown in Table 1. The diameters were averaged by infection classes for each year mentioned, and the difference was computed as the growth during the 5-year period or the periodic accretion. The average growth per year during the period considered is termed the periodic annual accretion. The data show an almost consistent decrease in the rate of diameter growth of black jack varying with the degree of mistletoe infection. The slight inconsistency exhibited in the rate of diameter growth of the o and x infection classes might be explained by the fact

that of the 27 trees in the former class, 11 per cent were isolated trees which did not form a part of the forest canopy, 28 per cent were dominant, 57 per cent were codominant and 4 per cent were intermediate trees, while with the latter infection class 60 per cent were isolated trees which did not form a part of the forest canopy and 40 per cent of the trees were in the codominant crown class. Table 2 consistently shows a decrease in the rate of diameter growth of yellow pine which varies directly with the degree of mistletoe infection.

Table 3 shows the total volume growth or increment of the standing black jacks for the same 5-year period, grouped by infection classes. The total volumes were computed by applying a volume table based on diameter and total height to the dimensions of each tree as measured in 1910 and 1915. It was found from taper measurements that volume tables could safely be applied to the individual trees. The volumes of all trees were totaled by infection classes. The difference between the total volumes at each time of measurement represents the periodic increment and the average volume growth per year during the period considered is the periodic annual

TABLE 1 -- Comparison of the average diameter growth or accretion of 58 standing black jacks, for a 5-year period, grouped according to degree of mistletoe infection.

Degree of Infection	Diameter Breast High: 1910	Diameter Breast High: 1915	Accretion, 1910-1915: Periodic	Accretion, 1910-1915: Periodic Annual	Basis
	Inches	Inches	Inches	Inches	No. of Trees
0	16.16	16.97	.81	.16	27
x	17.65	18.63	.98	.20	6
xx	15.82	16.57	.75	.15	15
xxx	14.24	14.36	.12	.02	10

TABLE 2 -- Comparison of the average diameter growth or accretion of 33 standing yellow pines, for a 5-year period, grouped according to degree of mistletoe infection.

Degree of Infection	Diameter Breast High: 1910	Diameter Breast High: 1915	Accretion, 1910-1915: Periodic	Accretion, 1910-1915: Periodic Annual	Basis
	Inches	Inches	Inches	Inches	No. of Trees
0	24.60	25.30	.70	.14	9
x	25.56	26.04	.48	.10	8
xx	22.14	22.44	.30	.06	7
xxx	21.49	21.61	.12	.02	9

increment. Table 4 shows the increment of the standing yellow pines for the same 5-year period. Both forms of western yellow pine exhibit a consistent decrease in the increment of those trees which are infected with mistletoe varying directly with the degree of infection.

Bole measurements were made at 16-foot intervals to insure greater accuracy in the study of the effect of mistletoe on the growth of the merchantable contents of the bole of the tree. Table 5 gives a comparison of the diameter growth of the bole of 33 trees at 4.5, 17 and 33 feet above ground. The comparative increments of the same trees is shown in Table 6. The apparent discrepancy between the rate of growth of the uninfected and lightly infected classes, as was noted above, is apparently due either to the varying proportions of the trees among the different crown classes or it may be possible that the infection at first results in a slight stimulation of the tree. In computing the volumes, each section below the highest point of measurement was cubed as a cylinder and that portion above was considered as the top of the tree and its volume was computed as that of a cone.

The growth of the standing trees was further checked by complete stem analyses of 102 felled trees. Sections

TABLE 3 -- Comparison of the total volume growth or increment of 58 standing black jacks, for a 5-year period, grouped according to degree of mistletoe infection.

Degree of Infection	Total Volume		Increment, 1910-1915			Basis
	1910	1915	Periodic	Periodic Annual		
	cu.ft.	cu.ft.	cu.ft.	cu.ft.	per cent	No. of Trees
0	987.2	1100.9	113.7	22.7	2.30	27
x	291.4	324.4	33.0	6.6	2.26	6
xx	434.0	470.6	36.6	7.3	1.68	15
xxx	234.9	243.2	8.3	1.7	.72	10

TABLE 4 -- Comparison of the total volume growth or increment of 33 standing yellow pines, for a 5-year period, grouped according to degree of mistletoe infection.

Degree of Infection	Total Volume		Increment, 1910-1915			Basis
	1910	1915	Periodic	Periodic Annual		
	cu.ft.	cu.ft.	cu.ft.	cu.ft.	per cent	No. of Trees
0	1151.0	1226.0	75.0	15.0	1.30	9
x	1206.0	1250.0	44.0	8.8	.75	8
xx	706.0	725.0	19.0	3.8	.54	7
xxx	801.0	809.0	8.0	1.6	.20	9 [a]

[a] Five trees of this class died during the 5-year period and were not included in the computation.

TABLE 5 -- Comparison of the average diameter growth or accretion of 33 standing black jacks, for a 5-year period, at 4.5, 17 and 33 feet from ground, grouped according to degree of mistletoe infection.

Degree of infection	Diameter outside bark						Accretion 1911-1916						Basis
	1911			1916			Periodic			Periodic Annual			
	4.5 ft.	17 ft.	33 ft.	4.5 ft.	17 ft.	33 ft.	4.5 ft.	17 ft.	33 ft.	4.5 ft.	17 ft.	33 ft.	
	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	No. of Trees
0	17.93	16.23	12.69	19.03	16.20	13.71	1.10	1.02	1.02	.22	.20	.20	16
x	22.25	19.59	14.14	23.40	20.85	15.25	1.15	1.26	1.11	.23	.25	.22	4
xx	15.92	13.30	8.65	16.78	13.91	9.46	.86	.61	.87	.17	.12	.16	7
xxx	15.47	14.42	9.19	17.15	14.64	9.51	.68	.22	.12	.13	.04	.02	6

TABLE 6 -- Comparison of the total volume growth or increment of 33 standing black jacks, for a 5-year period, grouped according to degree of mistletoe infection.

Degree of Infection	Total Volume		Increment, 1911-1916.			Basis
	1911	1916	Periodic	Periodic Annual		
	cu. ft.	cu. ft.	cu. ft.	cu. ft.	Per cent	No. of Trees
0	919.76	1047.40	127.64	25.53	2.77	16
x	359.07	410.65	51.58	10.32	2.87	4
xx	286.83	316.08	29.25	5.85	2.03	7
xxx	262.65	275.97	11.32	2.26	.85	6

were examined as near as possible to the surface of the ground, at 4.5 feet above the ground, and at every eight feet above this point. The measurements were recorded by 5-year periods instead of by decades as is the usual practice in complete stem analyses. The trees selected as near as possible from the same site, kind of stand, and the same age and crown classes. Only those trees free from abnormalities or other possible causes of deterioration or conditions deterrent to their growth were studies, thus permitting only two variables to enter into the results, namely, the age of the tree and the degree of mistletoe infection. The classification of the tree according to degree of infection represents the consensus of opinion of three different observers.

The basic data for each of the individual felled trees which were analyzed to show the effect of mistletoe on the growth and seed production of western yellow pine have been arranged in Table 7, according to the age of the trees. In compiling the stem analyses the data for each individual tree were computed separately. The diameters and heights of each tree for each fifth year, dating back from the year of analysis, were correlated with age in growth analysis diagrams, from which the dimensions of each tree for each integral five years of

TABLE 7 - Basic data for 107 felled trees showing the effect of mistletoe on the growth and seed production of western yellow pine.

Tree No.	Age	Diameter breast high	Diameter growth for last 5 yrs.	Total height	Height growth for last 5 yrs.	Total volume	Volume growth for last 5 yrs.	Degree of Infection [1]	Crown class [2]	Average length of leaves	Average length of leaf tufts	Seed crop 1915 [3]
	Yrs.	Ins.	Ins.	Ft.	Ft.	Cu. ft.	Cu. ft.			Ins.	Ins.	
58	23	4.0	1.5	15.5	4.5	1.81	.39	0	X	5.5	19.5	0
75	23	4.6	1.6	14.5	3.0	.84	.55	x	C	4.1	7.0	0
59	24	2.8	.7	13.5	3.5	.27	.08	0	C	5.6	19.3	0
74	24	3.2	1.0	13.5	3.5	.36	.17	0	C	5.1	11.6	0
67	25	1.9	.4	9.0	1.0	.11	.03	xx	C	2.6	5.0	0
62	26	2.4	.6	13.5	3.0	.22	.11	0	C	4.0	9.6	0
70	26	2.0	1.0	11.5	3.5	.12	.06	0	D	5.1	8.0	0
85	27	--	--	3.1	.5	.01	.001	xxx	X	3.0	3.3	0
72	28	2.4	1.2	11.5	4.0	.19	.09	0	D	6.0	10.3	0
73	28	6.2	1.8	24.5	4.5	2.02	.99	0	C	5.8	11.3	0
86	28	---	---	3.2	.8	.021	.014	xxx	X	3.6	5.3	0
84	29	---	---	2.8	.3	.009	.001	xxx	X	2.8	3.4	0
60	30	5.4	.6	23.5	3.0	1.58	.47	x	D	4.1	10.0	0
69	30	1.9	.4	9.5	2.0	.09	.01	x	I	3.3	4.3	0
71	30	5.4	1.6	17.5	4.0	.88	.32	0	C	5.6	11.3	0
22	30	4.8	1.8	17.5	4.5	.98	.53	0	D	5.6	23.5	0
65	31	4.6	1.0	17.5	3.0	.80	.29	x	C	4.1	8.6	0
15	31	---	---	3.5	1.0	.07	.06	x	X	3.8	9.3	0
68	32	3.5	.2	10.5	1.0	.41	.13	xx	X	2.1	3.3	0
17	33	---	---	3.0	.5	.01	.002	xx	X	---	---	0
61	33	4.8	.5	16.0	1.5	1.06	.27	xxx	C	2.7	5.5	0
64	33	3.0	.5	13.5	2.0	.83	.13	xx	I	3.3	10.3	0
63	35	.5	.2	5.5	.5	.09	.02	xxx	I	2.3	3.0	0
66	35	4.0	1.2	17.5	3.5	1.05	.43	x	C	4.1	8.6	0

[1] - Degree of infection classified as follows: 0=healthy trees without mistletoe, x=light mistletoe infection, xx=medium mistletoe infection, xxx= heavy mistletoe infection.

[2] - Crown class of trees classified as follows: X=Isolated, D=Dominant, C=Codominant, I=Intermediate, S=Suppressed.

[3] - Seed crop classified as follows: H=Heavy, G=Good, M=Medium, L=Light, O=None.

TABLE 7 -- Basic data for 107 felled trees showing the effect of mistletoe on the growth and seed production of western yellow pine (Continued)

Tree No.	Age	Diameter breast high	Diameter growth for last 5 yrs.	Total height	Height growth for last 5 yrs.	Total volume	Volume growth for last 5 yrs.	Degree of Infection[1]	Crown class[2]	Average length of leaves	Average length of leaf tufts	Seed crop 1915[3]
	Yrs.	In.	In.	Ft.	Ft.	Cu.ft.	Cu.ft.			In.	In.	
83	57	-	-	43	.7	.014	.002	xxx	X	5.1	2.8	0
107	77	7.1	-	21.0	-	2.40	-	0	D	5.2	3.5	0
18	89	5.1	1.1	16.0	3.0	1.78	.69	0	X	5.3	13.0	0
20	46	6.2	1.1	17.5	2.0	1.85	.63	xx	X	3.7	4.7	0
19	58	6.2	.8	27.0	3.0	3.11	1.05	x	X	5.6	17.0	0
29	60	15.6	1.5	47.5	3.5	21.24	5.05	0	X	6.8	13.3	0
47	65	13.2	1.6	51.5	5.0	19.79	4.69	0	C	5.3	8.0	1
81	65	10.8	1.3	46.0	4.5	11.22	3.39	0	C	5.8	22.3	0
82	65	9.0	.4	33.0	1.5	5.09	.76	xxx	C	4.1	6.6	0
52	66	11.2	.4	30.5	.5	6.14	.99	xx	X	3.5	5.0	0
89	66	7.9	.7	35.5	2.5	3.35	.72	x	X	4.6	7.7	0
48	69	10.8	1.1	39.0	2.5	9.09	2.11	xx	C	4.5	6.0	0
57	70	15.8	2.0	60.0	5.0	27.38	6.12	0	C	6.3	7.3	1
80	70	8.8	1.0	37.5	1.5	6.68	.94	0	C	6.6	7.5	0
85	71	7.5	.6	34.5	1.5	4.29	.47	x	C	4.3	6.7	0
8	72	4.4	.8	17.0	1.0	.85	.11	xx	I	3.6	-	0
46	72	15.6	1.1	42.5	3.0	19.84	2.59	0	X	6.1	10.6	0
87	74	7.0	.1	20.0	1.0	1.66	.08	xxx	X	3.5	3.1	0
21	75	7.4	.4	30.0	.5	3.77	.49	xxx	X	2.6	2.5	0
98	76	19.5	1.5	60.5	3.5	40.70	4.79	0	C	5.0	6.7	0
10	78	11.8	.4	36.5	.5	10.17	.67	xx	X	4.5	-	-
77	78	11.7	.5	38.5	.5	10.68	1.08	xxx	X	3.6	5.3	0
49	79	9.5	.3	32.5	1.0	5.47	.55	xxx	C	4.0	4.6	0
78	79	5.4	.4	26.0	1.0	2.08	.45	xx	S	3.5	4.3	0
104	79	14.5	-	42.0	-	19.00	-	0	X	3.8	6.2	1
1	80	12.6	.2	39.5	.7	14.60	1.15	xxx	X	-	-	0
11	80	10.8	1.5	34.5	2.5	7.82	2.21	0	X	6.3	18.0	0
105	80	7.5	-	30.0	-	2.50	-	xxx	X	2.8	4.2	0

TABLE 7 - Basic data for 107 felled trees showing the effect of mistletoe on the growth and seed production of western yellow pine. (Continued)

Tree No.	Age	Diameter breast high	Diameter growth for last 5 yrs	Total height	Height growth for last 5 yrs.	Total volume	Volume growth for last 5 yrs.	Degree of Infection[1]	Crown class[2]	Average length of leaves	Average length of leaf tufts	Seed crop 1915
	Yrs.	In.	In.	Ft.	Ft.	Cu.ft.	Cu.ft.			In.	In.	g
5	82	8.0	.4	33.5	.5	5.91	.33	xxx	C	---	---	0
9	82	10.6	.2	44.5	.5	9.64	.43	xx	X	3.6	---	0
44	82	11.2	.6	39.0	2.5	9.07	1.56	x	C	4.3	5.0	0
90	82	6.9	.3	28.5	.5	2.46	.36	x	C	4.3	5.3	0
6	83	10.8	1.5	47.5	4.0	10.67	2.76	0	D	5.8	---	0
38	83	9.8	.2	37.5	.2	7.65	.30	xxx	X	3.3	5.0	0
105	83	8.1	---	26.0	---	3.55	---	xxx	C	3.5	4.2	0
106	83	15.2	---	49.0	---	22.50	---	0	C	5.5	6.1	L
54	84	7.1	.5	27.5	2.0	2.51	.37	xxx	C	4.3	4.6	0
43	85	8.2	.3	40.5	2.5	6.65	1.23	xx	C	4.1	5.0	0
51	85	14.4	1.2	47.5	3.0	21.19	3.62	0	C	5.6	8.0	0
24	87	11.1	1.6	41.5	4.0	10.93	2.84	0	X	6.0	22.0	0
79	88	5.8	.4	24.5	.5	1.87	.23	xxx	S	4.1	5.6	0
14	89	10.4	.5	35.5	2.0	7.84	.98	xxx	D	3.6	5.7	---
53	92	14.0	1.1	46.5	2.5	16.00	2.69	0	C	5.6	8.6	L
13	93	7.8	.2	32.5	.5	4.26	.27	xx	X	5.1	7.8	0
23	93	6.8	.1	22.5	1.0	2.30	1.80	xxx	C	3.1	3.3	0
91	93	8.9	.4	36.0	1.0	5.65	1.01	x	X	4.5	6.5	0
2	94	12.0	1.5	40.5	1.0	15.18	4.40	0	X	---	---	0
42	94	14.8	.2	41.5	.5	20.03	.67	xxx	X	4.5	5.6	0
76	94	9.8	.7	39.0	1.0	7.80	.77	xxx	C	3.1	4.6	0
7	95	4.0	.1	21.0	1.0	.84	.16	xxx	S	4.1	---	0
56	95	14.4	.3	42.5	1.0	16.37	.42	xxx	C	4.0	5.0	0
87	97	9.0	.5	43.0	1.0	7.06	.85	x	C	4.6	5.3	0
28	98	18.1	1.5	64.5	6.0	47.49	6.48	x	X	6.3	11.3	0
25	100	8.3	.2	30.0	.5	4.23	.28	xxx	D	4.5	3.6	0

TABLE 7- Basic data for 107 felled trees showing the effect of mistletoe on the growth and seed production of western yellow pine (continued).

Tree No.	Age	Diameter breast high	Diameter growth for last 5 yrs.	Total height	Height growth for last 5 yrs.	Total volume	Volume growth for last 5 yrs.	Degree of infection[1]	Crown class[2]	Average length of leaves	Average length of leaf tufts	Seed crop 1915[3]
	Yrs.	In.	In.	Ft.	Ft.	Cu. ft.	Cu. ft.			In.	In.	
55	100	14.6	.2	49.5	1.0	20.05	1.08	xxx	C	5.2	5.5	0
99	102	20.6	1.0	64.5	3.0	52.44	6.81	0	C	4.7	6.3	0
12	104	12.4	.5	41.5	1.5	13.13	1.17	0	X	5.3	6.1	0
93	104	21.6	1.1	73.0	3.5	63.47	5.73	0	C	4.8	5.7	L
95	105	20.4	.6	60.5	1.5	62.11	4.30	x	C	5.2	7.2	0
40	106	9.4	.8	53.0	3.0	8.62	.92	xx	C	5.3	6.6	0
39	112	11.6	1.2	62.0	3.5	18.82	5.59	0	C	5.0	10.6	0
96	114	18.8	.6	70.5	1.0	43.68	1.64	xx	C	4.3	6.8	0
94	117	20.4	1.0	78.0	3.0	69.85	5.05	0	C	5.1	6.2	L
45	120	19.4	.4	67.0	1.0	42.59	1.32	xx	C	4.3	3.6	0
97	120	22.4	1.7	79.5	2.5	83.56	11.32	0	C	5.4	6.8	L
41	121	11.9	.8	58.0	1.0	16.10	1.09	xxx	C	5.3	6.6	0
27	123	17.6	.1	46.5	.5	21.86	.58	xxx	X	4.6	5.1	0
4	124	20.2	1.7	68.5	1.0	67.68	9.40	0	X	6.0	9.0	0
92	125	17.1	.4	68.0	1.0	43.33	3.75	xx	C	5.1	5.0	0
3	126	20.3	.3	55.5	.3	42.03	1.49	xxx	X	4.0	2.5	0
50	130	23.4	2.3	79.5	1.5	92.78	8.56	0	D	5.0	8.3	M
26	134	18.2	.2	45.0	0.5	25.23	.82	xxx	D	3.6	2.5	0
16	138	20.2	.4	59.5	.5	50.01	3.74	x	X	5.1	11.5	0
36	214	19.2	1.2	67.5	1.5	44.90	4.27	0	C	5.6	7.1	L
102	214	23.0	1.4	85.0	1.0	108.80	7.98	0	D	5.5	5.3	M
33	217	15.2	.5	58.5	1.0	32.92	2.62	xxx	X	4.7	8.3	L
30	218	18.2	.4	78.5	.2	59.68	2.55	xxx	C	3.5	---	0
100	218	20.8	.5	77.5	1.5	71.92	2.63	0	C	5.3	5.2	0
101	218	25.6	1.3	87.5	1.0	133.67	10.17	0	X	4.8	5.8	L
31	220	16.0	.1	84.5	.3	54.91	1.15	xxx	C	5.0	7.1	0
32	220	21.6	.8	87.5	1.0	90.26	7.06	0	D	5.8	7.3	M
34	230	25.6	.4	76.5	.3	107.47	2.88	xxx	X	5.2	8.8	0
35	233	17.6	.2	72.0	.5	65.10	5.68	xxx	C	4.5	5.6	0

age or quinquennium were read.

Figure 1 shows the graphical growth analysis diagram for Tree No. 4, a typical healthy western yellow pine, while Figure 2 shows the same kind of a diagram for Tree No. 27, which was heavily infected with mistletoe. Both trees grow within a short distance of each other on the same site, they were of practically the same age and both belonged to the isolated crown class and the 101 to 140-year age class; therefore, these factors cannot be held accountable for the material falling off in the increment of the heavily infected tree. The very marked decrease in the rate of growth during the last 30 years evidently due to the parasitism of the mistletoe is very clearly shown by the closeness of the last seven quinquennial lines near the outside of the cone in Figure 2, which represents the growth of Tree No. 27.

A complete set of curves was drawn for each tree relating diameter breast high, total height and volume to age. This curving eliminated the irregularities and irrelevant abnormalities occurring in each tree. The data for the individual trees were then averaged by a series of harmonized curves for each infection and 40-year

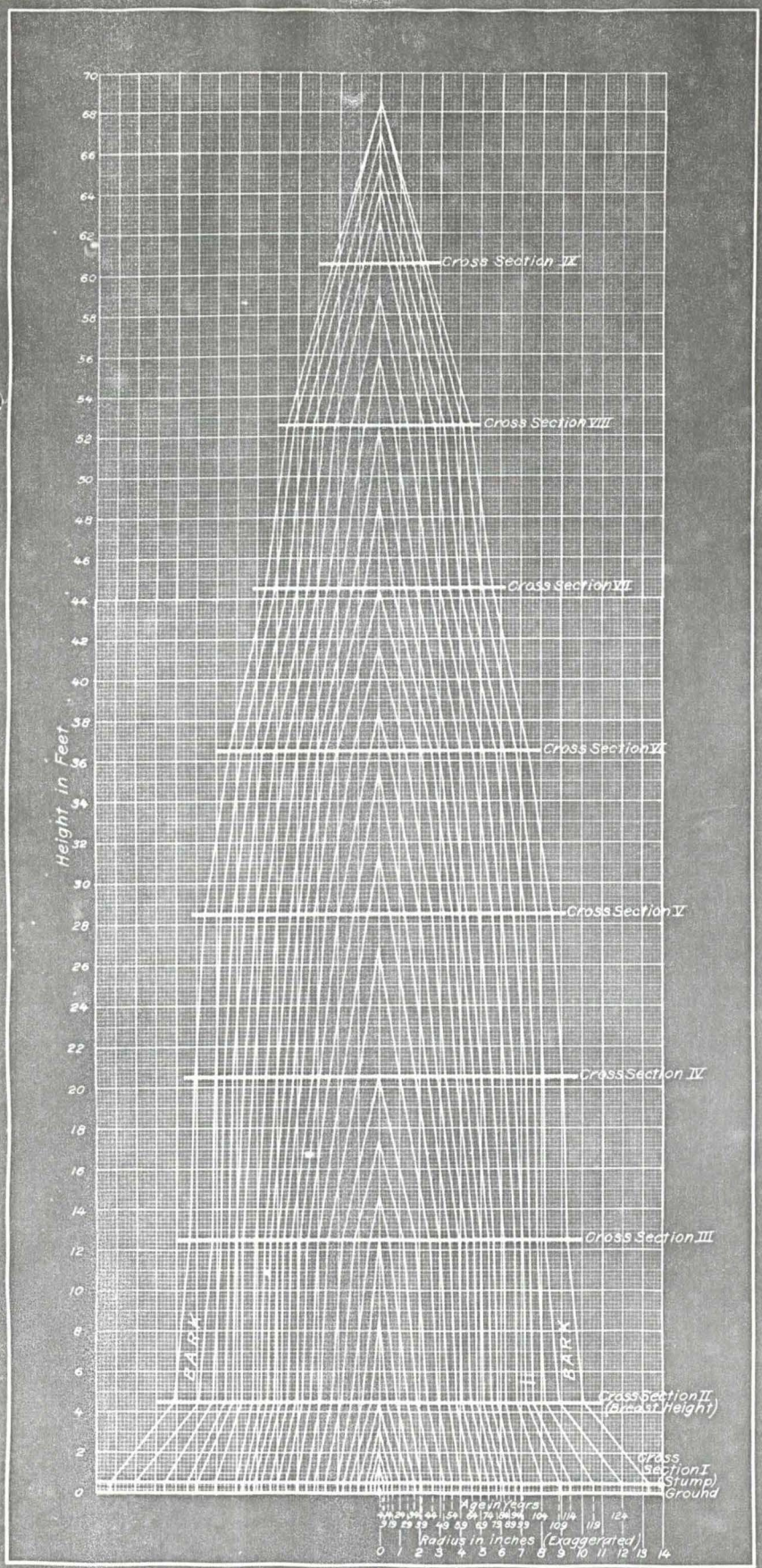


FIG. 1. GRAPHIC REPRESENTATION OF THE GROWTH ANALYSIS OF FELLED TREE NO. 4, A SOUND HEALTHY WESTERN YELLOW PINE (HEIGHT GREATLY REDUCED IN PROPORTION TO DIAMETER)

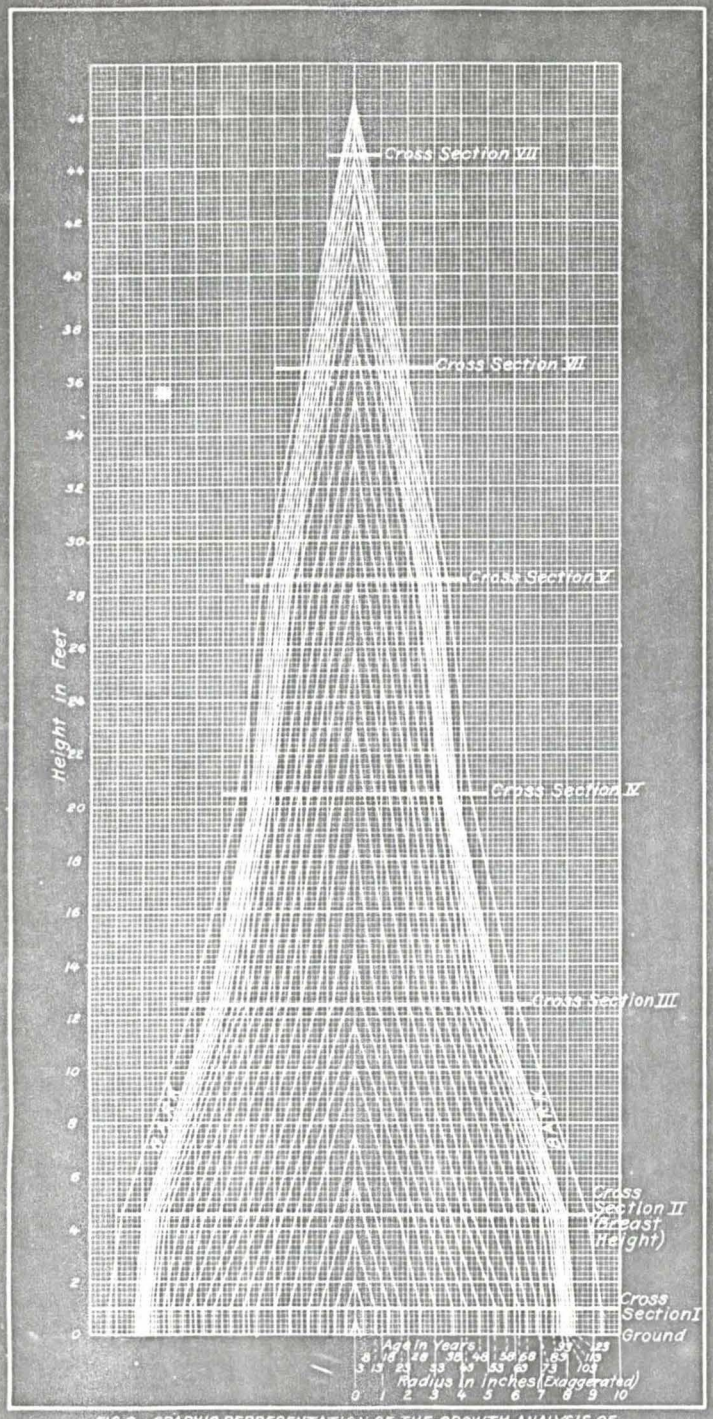


FIG. 2. GRAPHIC REPRESENTATION OF THE GROWTH ANALYSIS OF FELLED TREE NO. 27, A WESTERN YELLOW PINE HEAVILY INFECTED WITH MISTLETOE (HEIGHT GREATLY REDUCED IN PROPORTION TO DIAMETER)

age class. Forty-year age classes were used instead of the usual 20-year age classes because this provided a greater number of trees as the basis for each age and infection class.

The harmonized volume-age curves for the 21 to 60 and the 61 to 100-year age classes are shown in Figure 3, which indicates that the mistletoe infection was sufficiently severe to retard the rate of growth of the more heavily-infected trees of these two age classes by approximately 20 years. Figure 4, shows a similar retardation of the increment for the 101 to 140 and the 201 to 240-year age classes except that the rate of growth of the more heavily-infected trees of these age classes has been on the decline for the past 70 to 80 years. The curves in both figures show conclusively that the current increment is directly dependent upon the degree of mistletoe infection. Generally speaking the degree of mistletoe infection increases with the length of time which a tree has been infected.

A further comparison of the average diameter growth or accretion of the felled western yellow pine trees for the 25-year period from 1890 to 1915 grouped

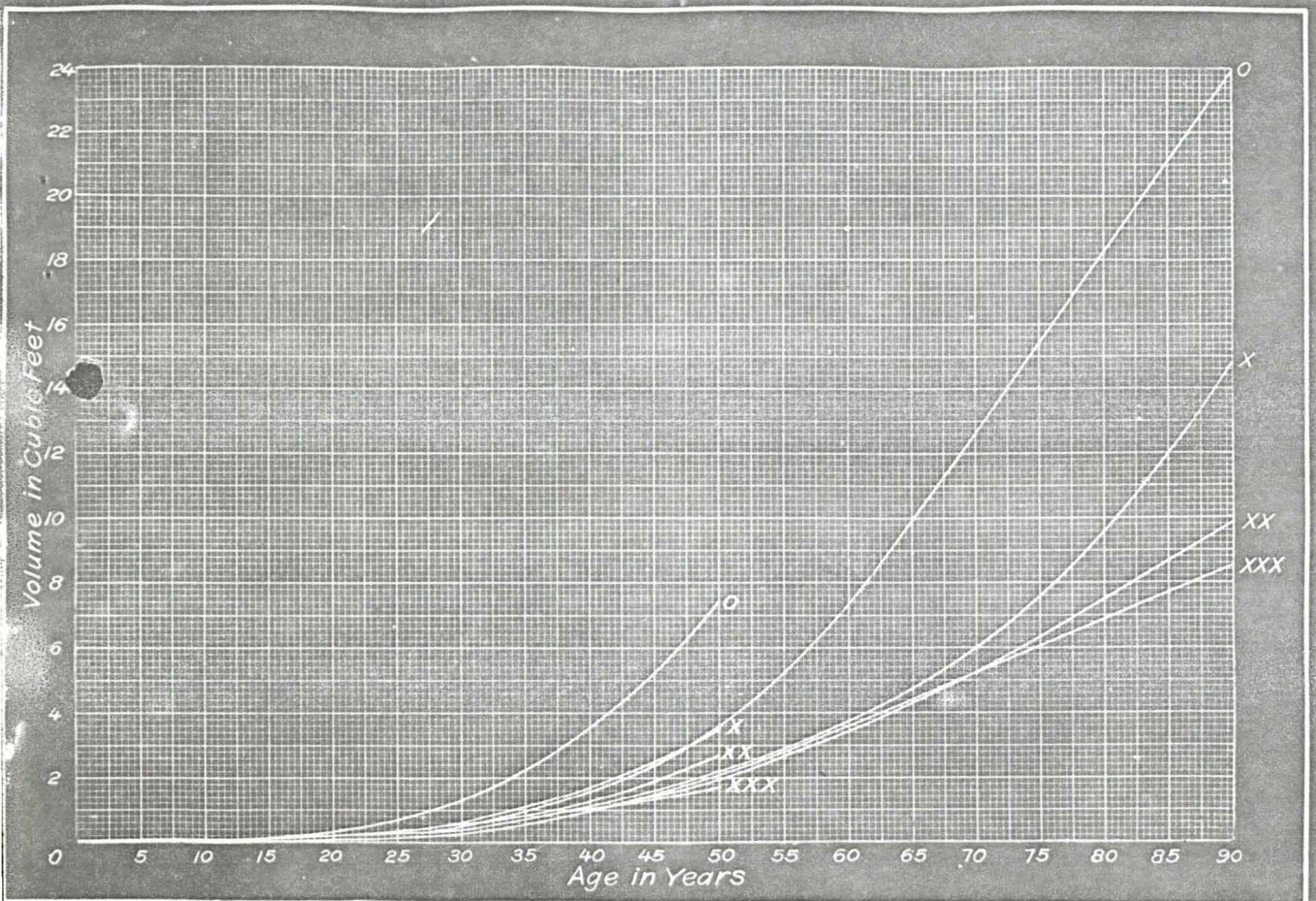


FIG. 3. VOLUME-AGE CURVES SHOWING THE EFFECT OF THE FOUR DEGREES OF MISTLETOE INFECTION ON THE 21-60 AND THE 61-100 YEAR AGE CLASSES

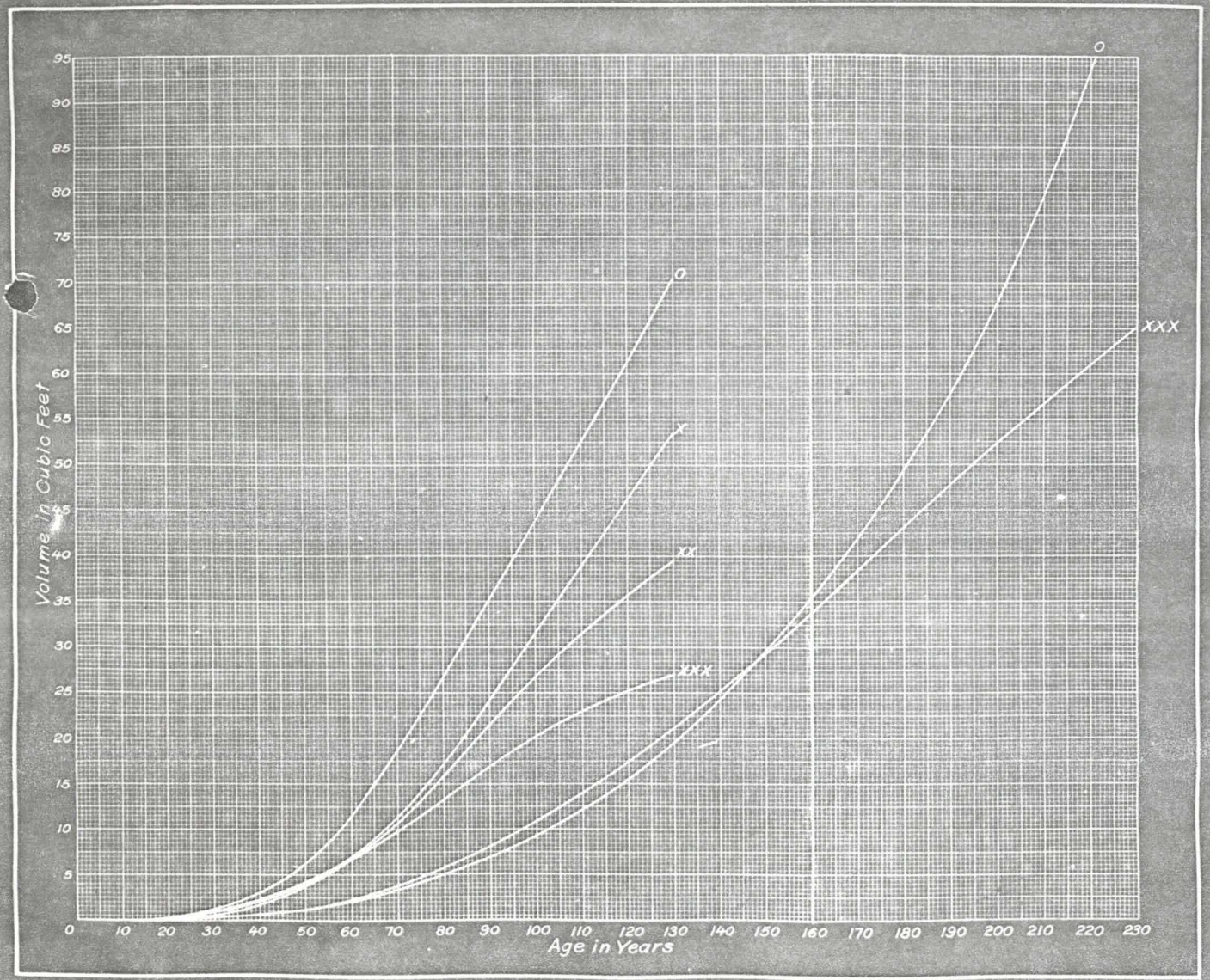


FIG. 4. VOLUME-AGE CURVES SHOWING THE EFFECT OF THE DIFFERENT DEGREES OF MISTLETOE INFECTION ON THE 101-140 AND THE 201-240 YEAR AGE CLASSES

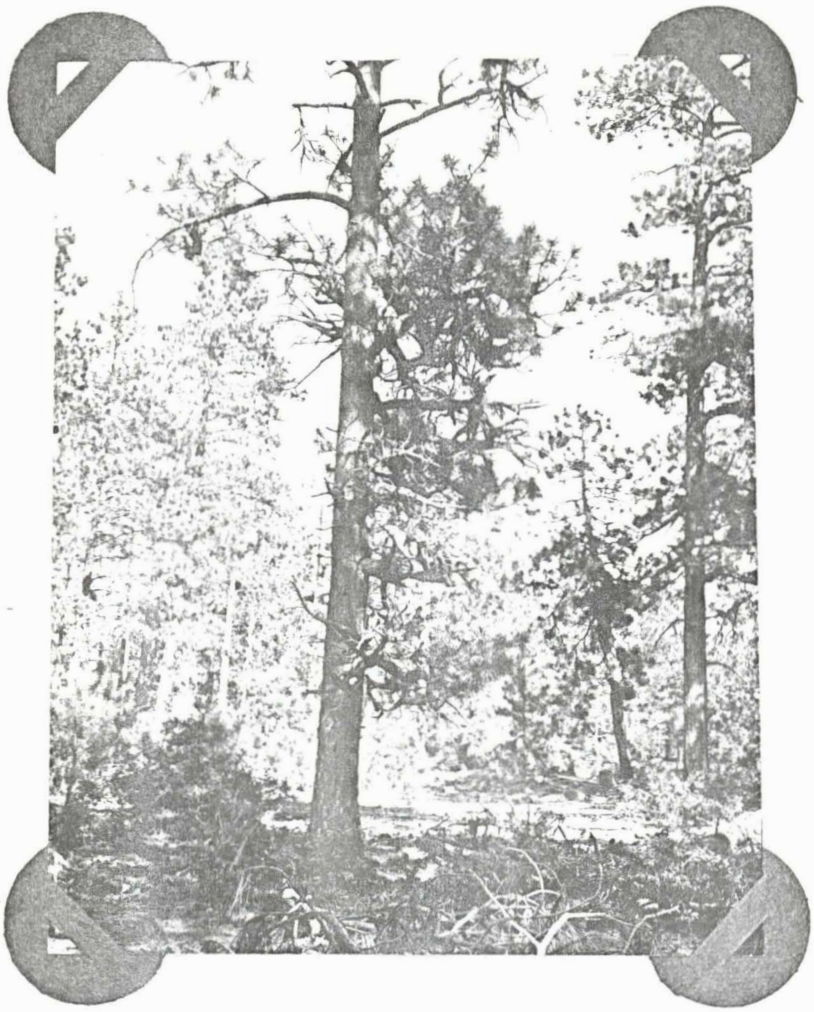


Fig. 5. A western yellow pine tree showing stunted branches and witches' brooms in the lower part of the crown caused by mistletoe. Santa Fe National Forest, New Mexico.

Fig. 6. A western yellow pine tree recently killed by mistletoe. Coconino National Forest, Arizona.

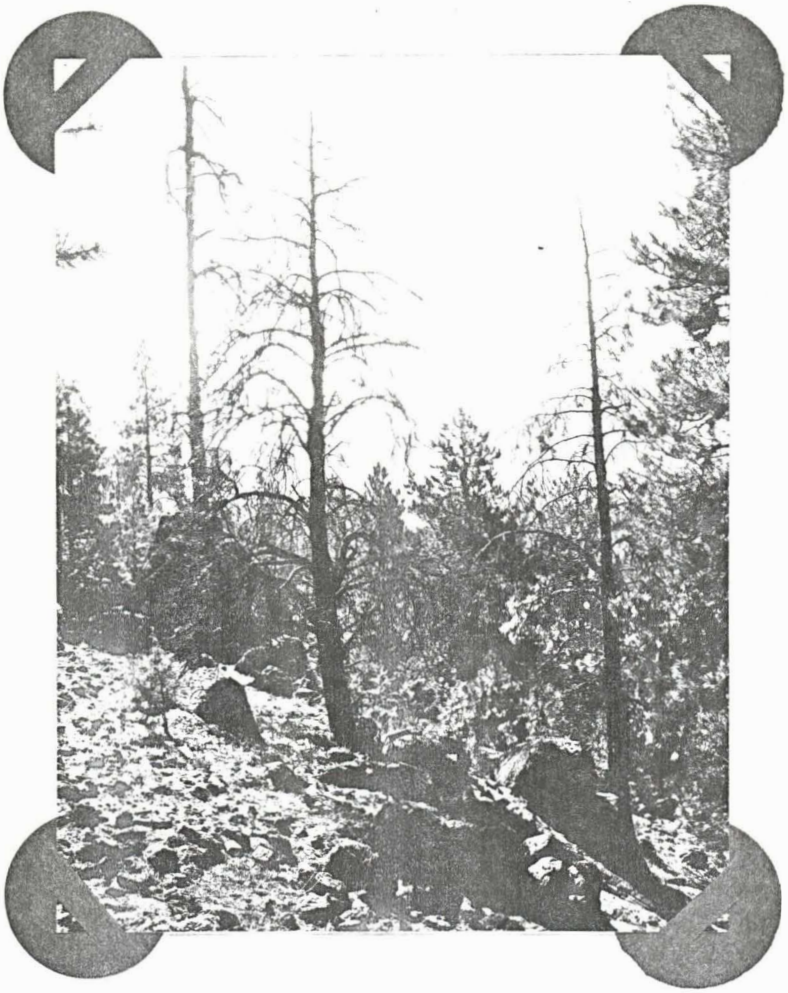


Fig. 7. Two "black jacks" in the foreground and a "yellow pine" in the background killed by mistletoe. The "black jacks" were killed recently while the "yellow pine" has been dead for a number of years. Coconino National Forest, Arizona.

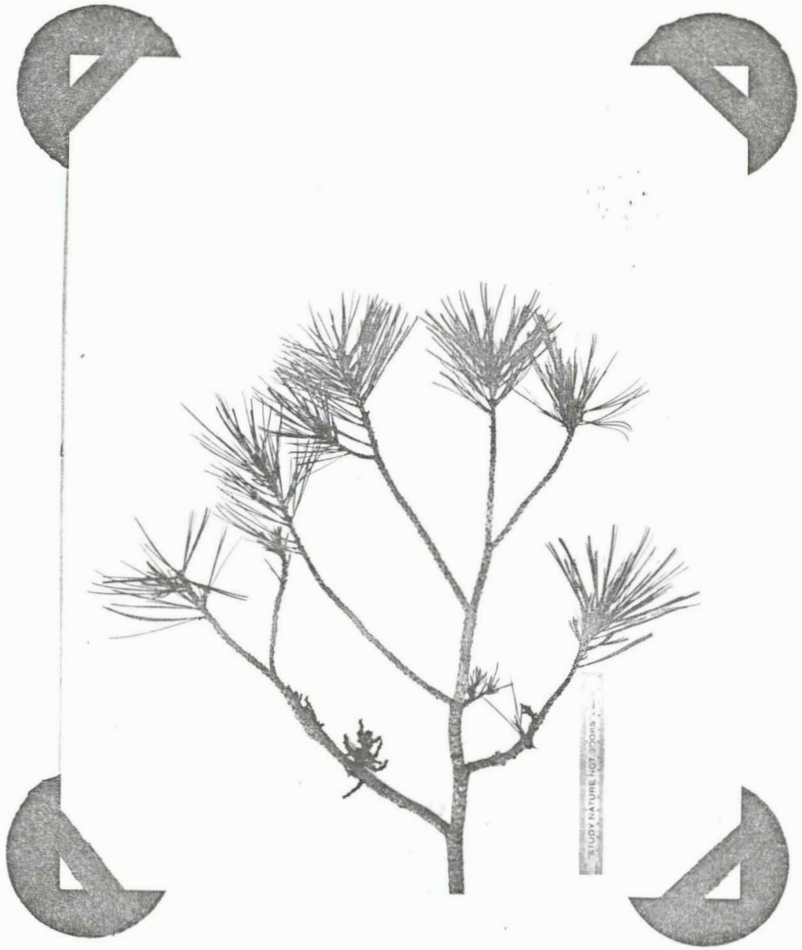


Fig. 8. A small branch of western yellow pine showing fewer and smaller leaves and shorter internodes due to the mistletoe, of which three local infections may be seen. 1/6 natural size.

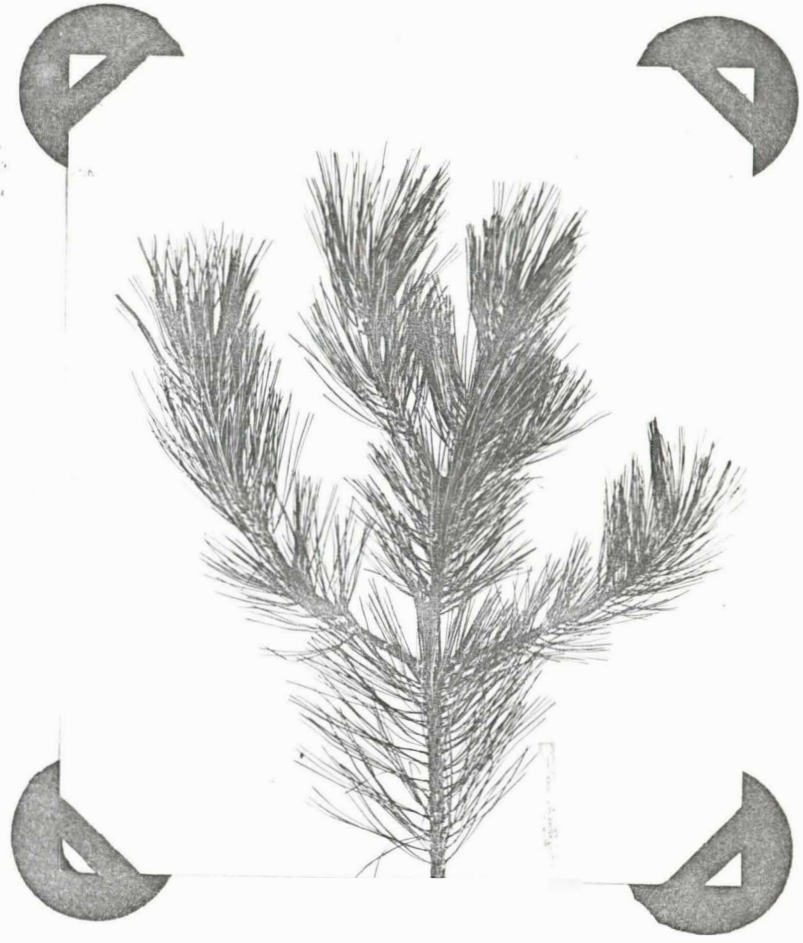
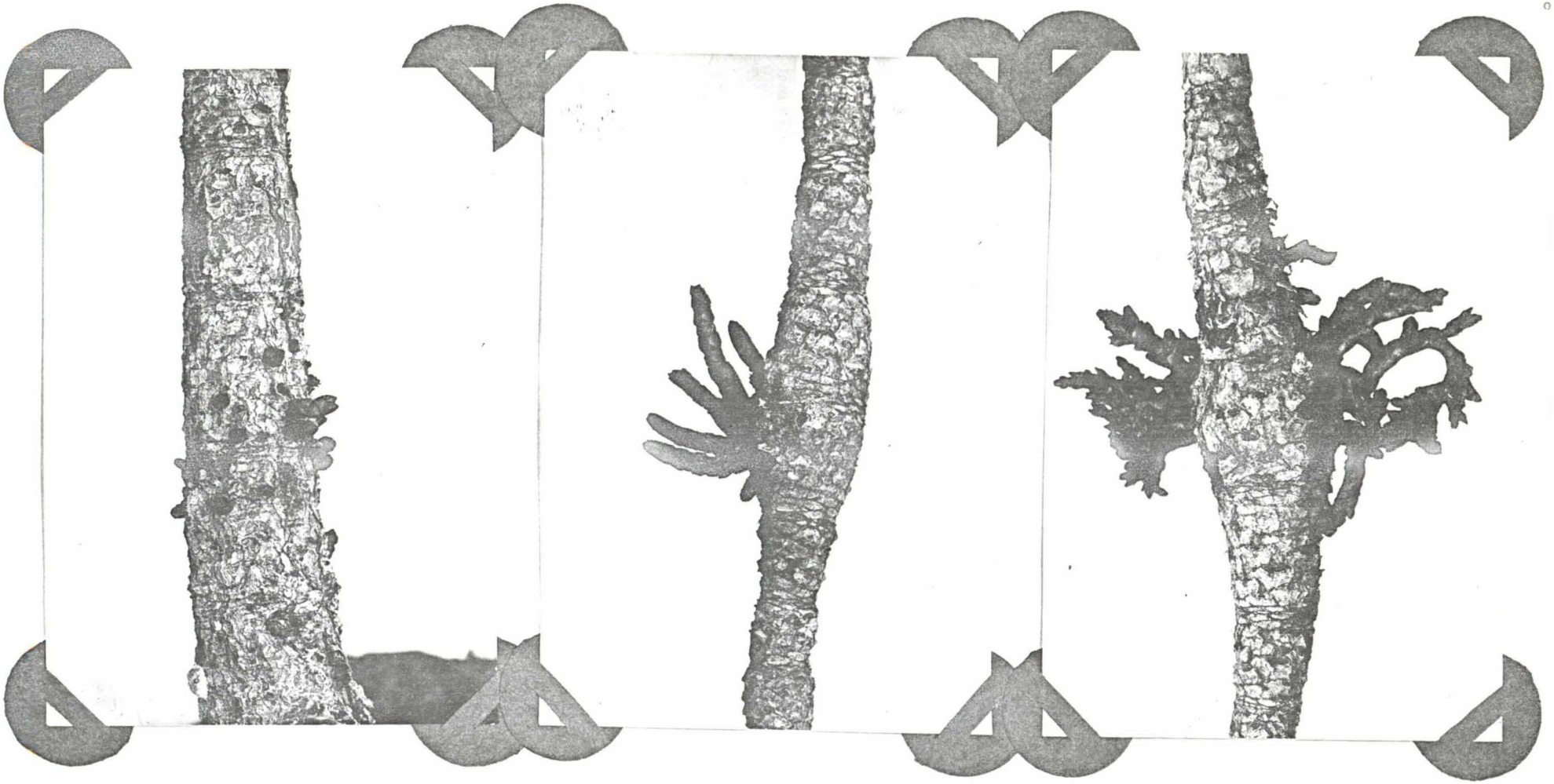


Fig. 9. A small branch of western yellow pine showing the larger leaves and longer internodes developed on a healthy tree in the same group from which the branch shown in Fig. 8 was secured. 1/3 natural size.



Figs. 10-12. Showing three successive states in the early development of mistletoe on twigs of western yellow pine and the formation of swellings resulting from mistletoe infection. x 1½

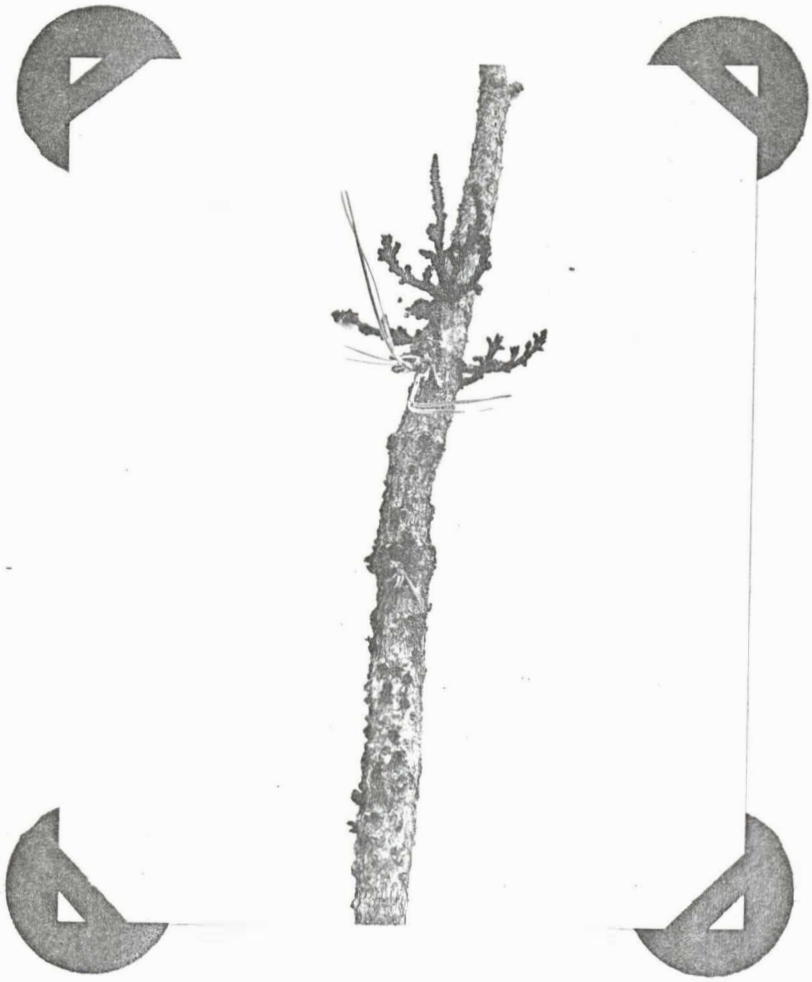


Fig. 13. Showing the advance of a mistletoe lesion on a twig of western yellow pine; dead stems of early infection in the center and young, vigorous mistletoe plants at the upper edge of the lesion.

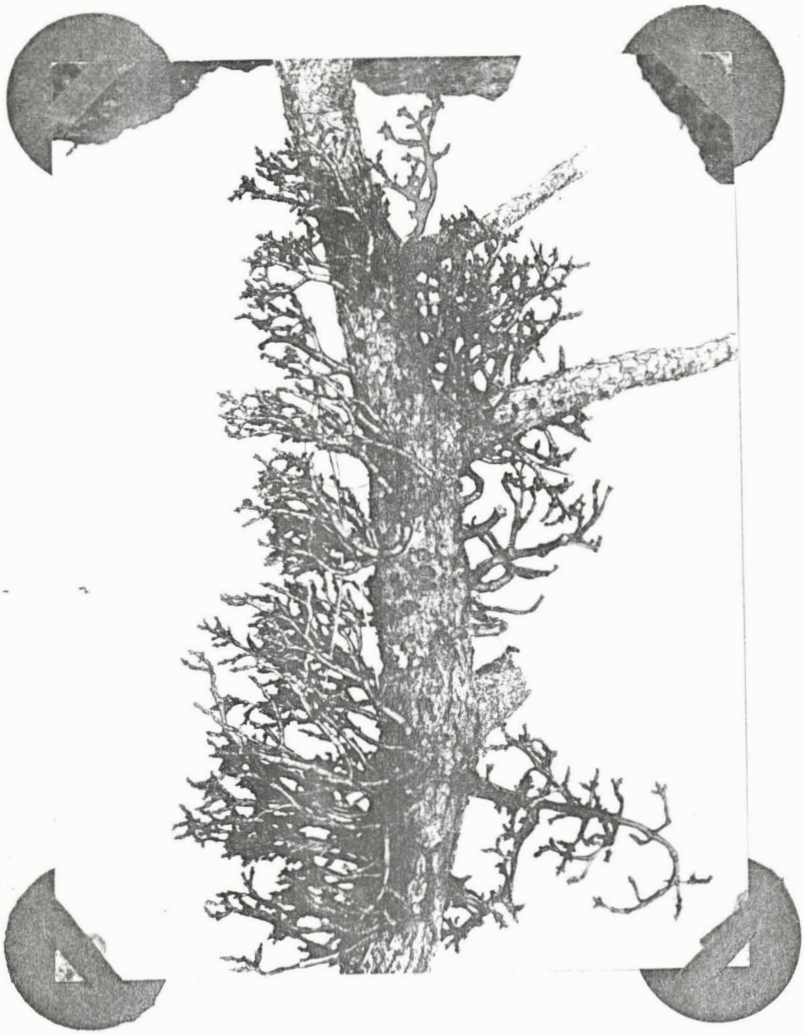


Fig. 14. Showing a typical mistletoe colony on western yellow pine. The stubs of dead and dying mistletoe plants are in the center and the youngest plants are seen at each end of the lesion.

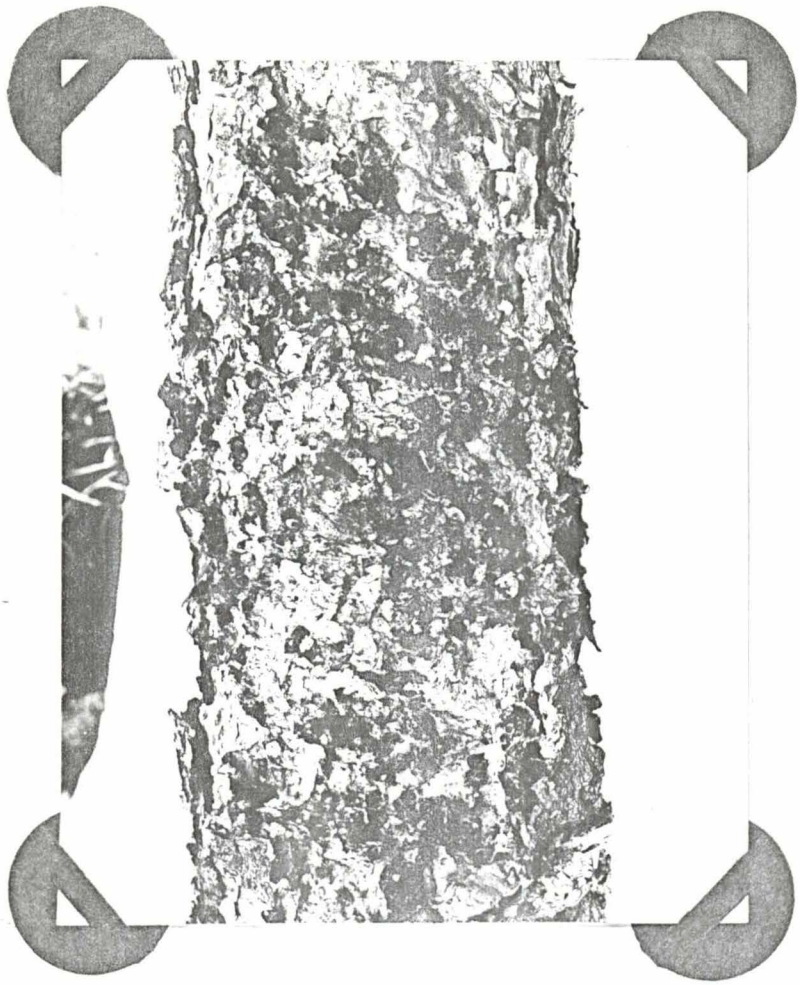


Fig. 15. Showing concentric ridge of advance of a mistletoe lesion on western yellow pine.

TABLE 9 -- Comparison of the average height growth or accretion of 102 felled western yellow pine trees, for a 25-year period, grouped by age classes and degree of mistletoe infection.

Age Class	Degree of Infection	Total Height 1890	Total Height 1895	Accretion Periodic Annual 1890-95	Total Height 1900	Accretion Periodic Annual 1895-1900	Total Height 1905	Accretion Periodic Annual 1900-05	Total Height 1910	Accretion Periodic Annual 1905-10	Total Height 1915	Accretion Periodic Annual 1910-15	Basis No. of Trees
Years		Feet	Feet	Feet	Feet	Feet	Feet	Feet	Feet	Feet	Feet	Feet	
21-60	0	3.2	5.4	.44	8.0	.52	11.3	.66	14.9	.72	18.6	.74	11
	x	2.6	5.1	.50	8.3	.64	12.2	.78	15.3	.62	18.2	.58	6
	xx	1.6	3.2	.32	4.6	.28	6.1	.30	7.4	.26	8.6	.24	7
	xxx	1.3	2.5	.24	3.8	.26	4.9	.22	5.7	.16	6.3	.12	5
61-100	0	27.4	31.5	.82	35.6	.82	39.5	.78	43.2	.74	46.6	.68	12
	x	29.6	32.2	.52	34.6	.48	36.8	.44	38.8	.40	40.8	.40	7
	xx	23.7	26.1	.48	28.3	.44	30.5	.44	32.1	.32	33.3	.24	9
	xxx	26.4	28.4	.40	30.0	.32	31.2	.24	32.2	.20	33.0	.16	17
101-140	0	58.9	61.5	.52	64.2	.54	66.9	.54	69.7	.56	72.5	.56	6
	x	49.4	51.8	.48	53.5	.34	55.0	.30	56.4	.28	57.5	.22	4
	xx	55.8	57.9	.42	60.0	.42	61.9	.38	63.5	.32	65.0	.30	4
	xxx	46.4	47.8	.28	49.0	.24	50.0	.20	50.6	.12	51.2	.12	4
201-240	0	75.5	76.7	.24	77.8	.22	78.9	.22	80.0	.22	81.2	.24	5
	xxx	71.4	72.0	.12	72.5	.10	73.0	.10	73.5	.10	74.0	.10	5

TABLE 6 -- Comparison of the average diameter growth or accretion of 102 felled western yellow pine trees, for a 25-year period, grouped by age classes and degree of mistletoe infection.

Age Class	Degree of Infection	Diameter breast high 1890	Diameter breast high 1895	Accretion 1890-95 Periodic Annual	Diameter breast high 1900	Accretion 1895-1900 Periodic Annual	Diameter breast high 1905	Accretion 1900-05 Periodic Annual	Diameter breast high 1910	Accretion 1905-10 Periodic Annual	Diameter breast high 1915	Accretion 1910-15 Periodic Annual	Basis
Yrs.		Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	No. of Trees
21-60	0	.8	1.0	.04	1.6	.12	2.3	.14	3.7	.28	5.0	.26	11
	x	.2	.6	.08	1.4	.16	2.5	.22	3.5	.20	4.4	.18	6
	xx	.1	.4	.10	.8	.08	1.3	.10	1.8	.10	2.1	.06	7
	xxx	—	.3	.06	.6	.06	.7	.02	.9	.04	1.1	.04	5
61-100	0	7.2	8.2	.20	9.3	.22	10.4	.22	11.5	.22	13.0	.30	12
	x	6.6	7.3	.14	8.0	.14	8.7	.14	9.3	.12	9.9	.12	7
	xx	6.0	6.8	.16	7.5	.14	8.1	.12	8.6	.10	9.0	.08	9
	xxx	6.8	7.5	.14	8.2	.14	8.7	.10	9.2	.10	9.4	.04	17
101-140	0	15.0	15.7	.14	16.5	.16	17.5	.20	18.6	.22	19.8	.22	6
	x	14.5	15.1	.12	15.9	.16	16.7	.16	17.5	.16	18.3	.16	4
	xx	14.8	15.2	.08	15.7	.10	16.1	.08	16.5	.08	16.9	.08	6
	xxx	15.2	15.6	.08	15.9	.06	16.3	.08	16.7	.08	17.0	.06	4
201-240	0	17.8	18.5	.14	19.3	.16	20.1	.16	21.1	.20	22.1	.20	5
	xxx	16.7	17.0	.06	17.4	.08	17.7	.06	17.9	.04	18.2	.06	5

TABLE 10. - Comparison of the average volume growth or increment of 102 felled western yellow pine trees, for a 25-year period, grouped by age classes and degree of mistletoe infection.

Age Class	Degree of Infection	Total Volume 1890	Total Volume 1895	Increment 1890 - 95 Periodic Annual Cu.Ft.	Increment 1890 - 95 Periodic Annual Percent	Total Volume 1900	Increment 1895 - 1900 Periodic Annual Cu.Ft.	Increment 1895 - 1900 Periodic Annual Per cent	Total Volume 1905	Increment 1900 - 05 Periodic Annual Cu. Ft.	Increment 1900 - 05 Periodic Annual Percent	Total Volume 1910	Increment 1905 - 10 Periodic Annual Cu.Ft.	Increment 1905 - 10 Periodic Annual Per cent	Total Volume 1915	Increment 1910 - 15 Periodic Annual Cu.Ft.	Increment 1910 - 15 Periodic Annual Percent	Basis No. of trees
Years		Cu.Ft.	Cu.Ft.	Cu.Ft.		Cu.Ft.	Cu.Ft.		Cu. Ft	Cu. Ft.		Cu. Ft	Cu.Ft.		Cu.Ft.	Cu.Ft.		
21-60	0	.36	.54	.036	[a]	.80	.052	[a]	1.19	.078	[a]	1.81	.124	[a]	2.67	.172	[a]	11
	x	.02	.05	.006		.20	.030		.41	.042		.86	.090		1.25	.078		6
	xx	.01	.02	.002		.08	.012		.14	.012		.24	.020		.37	.026		7
	xxx	-	-	-		.04	.008		.08	.008		.18	.020		.29	.022		5
61-120	0	3.77	5.40	.326	8.6	7.54	.428	7.9	10.23	.538	7.1	13.52	.658	6.4	17.28	.752	5.6	12
	x	4.90	5.91	.202	4.1	7.10	.238	4.0	8.49	.278	3.9	9.89	.280	3.3	11.49	.320	3.2	7
	xx	2.53	3.24	.142	5.6	3.98	.148	4.6	4.81	.166	4.2	5.65	.168	3.5	6.52	.174	3.1	9
	xxx	4.12	4.94	.164	4.0	5.72	.156	3.2	6.46	.148	2.6	7.12	.132	2.0	7.70	.116	1.6	17
101-140	0	35.10	39.78	.936	2.7	44.80	1.004	2.5	50.26	1.092	2.4	56.48	1.244	2.5	63.41	1.386	2.5	6
	x	25.95	30.15	.840	3.2	34.80	.930	3.1	39.20	.880	2.5	43.72	.904	2.3	48.07	.870	2.0	4
	xx	23.72	26.35	.526	2.2	28.62	.454	1.7	30.75	.426	1.5	32.70	.390	1.3	34.60	.380	1.2	4
	xxx	20.02	21.04	.204	1.0	22.87	.366	1.4	24.10	.246	1.1	25.32	.244	1.0	26.42	.220	.9	4
201-240	0	59.06	63.94	.976	1.7	69.36	1.088	1.7	75.72	1.268	1.8	82.46	1.348	1.8	90.12	1.532	1.9	5
	xxx	52.16	54.36	.440	.8	56.56	.440	.8	58.94	.476	.8	61.38	.488	.8	64.00	.524	.9	5

[a] The periodic annual increment per cent was not computed for the 21-60 year age class because of the extremely small initial volumes and the proportionately great effect on the percentage of slight individual variations.

by 40-year age classes and degree of mistletoe infection, is shown in Table 8. A similar comparison of the average height growth or accretion of the same trees is given in Table 9. Table 10 shows a comparison of the average volume growth or increment of the same trees for the same period, similarly grouped by age and infection classes. The 21 to 60, 61 to 100, and the 101 to 140-year age classes in Tables 8, 9 and 10 are composed entirely of black jacks while yellow pines constitute the 201 to 240-year age class.

In the early stages of the study the trees were segregated by crown classes. Since by far the greater part of the trees in the open park-like stands studies were in the isolated, dominant and codominant classes the effects of crown class were found to be negligible in contrast to the marked effect of mistletoe in retarding the rate of growth. The retardation of growth due to the mistletoe was consistently evident in each age-crown class in which sufficient trees were secured to form a comparable basis. It was impossible to secure an equal number or equal proportion of each crown class in each age-infection class. As has been shown it was found more necessary to segregate the felled trees by age-infection classes than

by crown-infection classes. It was impracticable to segregate by crown classes all of the trees used in this study because of the extremely small number and in some cases lack of trees, falling into each age-infection-crown class had such a triple classification been used. The diameter, height and volume growth or increment during the 5-year period 1910-1915, in the 21-60 year age class of the isolated trees included in Table 7, may be cited to show the injurious effect of mistletoe on growth within a given age-crown class, as follows:

Degree of Infection:	Breast High Diameter Growth for last 5 yrs.	Height Growth for last 5 years	Volume Growth for last 5 years	Basis
	Ins.	Ft.	Cu. Ft.	No. of trees:
o	1.3	3.3	2.04	3
x	0.8	2.0	0.54	2
xx	0.6	1.2	0.25	3
xxx	a	0.5	0.004	4

[a] The trees in this class were less than 4.5 ft. in height.

In Table No. 11 is shown increment data for two intensive sample plots aggregating 24 acres located within

Table 11. Data showing the effect of mistletoe infection on the rate of growth of western yellow pine on two intensive sample plots aggregating 24 acres on the Tusayan National Forest.

Degree of Infection	Avg. Diameter Growth 1914-1919	Periodic annual Increment 1914-1919	Periodic annual Increment per cent 1914-1919°	Total Volume of Class, 1919	Basis (No. of trees, 4" and over, d.b.h.
	Ins.	Cu. Ft.		Cu.Ft.	
0	0.70	4.56	2.54	1636.2	359
X	0.80	5.55	2.79	553.9	98
XX	0.49	2.23	1.83	254.5	114

Note: Since there were only 13 trees classed as moderately infected, they were omitted because of the small basis.

° On cubic foot basis.

the extensive plot on the Tusayan National Forest mentioned below, the data being grouped according to degree of infection. An accelerated growth is noted in the x infection class comparable to that noted in Table 1, the explanation of which is not evident from the data at hand, unless it be an actual stimulation due to the presence of the mistletoe. The decrease in the rate of growth in the heavily infected class is very marked and is in accord with all of the other results secured in this study.

Two seedlings, one healthy and the other heavily-infected with mistletoe, which were growing side by side on a good site, were analyzed and both found to be 15 years old. The healthy seedling showed marked vigor and was four feet tall, whereas the one infected with mistletoe was only three feet tall and showed evident stunting and that death was imminent.

The data presented in the preceding pages show that although minor fluctuations are exhibited, the rate of growth of the host decreases with the amount of mistletoe infection or in other words, is dependent on the degree of parasitism. Possible exceptions may be cases of very light infection which appear to act as stimulants for the host tree. These results are really to be expected when

the effects of mistletoe parasitism are fully understood.

Effect on Limbs:

The first visible effect of the infection of a limb by mistletoe is the formation of a fusiform swelling about the center of infection similar to those occasionally found on stems. This hypertrophy is the first stage of a later abnormal growth of branches from the enlarged portion, which results in the formation of witches' brooms. When the stimulus of the parasite has once become manifest through the formation of a broom the tendency toward abnormal branching continues although the aerial parts of the mistletoe may have died.

The comparative diameter growth or accretion of 54 limbs on 18 standing black jacks is averaged by infection classes in Table 12. Measurements were taken at six inches from the bole of the tree and at six-inch intervals beyond this point. The measurements taken at 6 to 18 inches from the bole of the tree were averaged and are presented in the table to facilitate a clearer and more comprehensive interpretation of the significant data. Limb measurements were also taken on the felled

TABLE 12. - Comparison of the average diameter growth or accretion of 54 limbs on 18 standing black jacks, for a 5-year period, grouped according to degree of mistletoe infection.

Degree of Infection	Average Diameter 1/		Accretion: 1910-1915		Basis
	1910	1915	Periodic	Periodic Annual	
	In.	In.	In.	In.	No. of limbs
0	3.84	3.98	.14	.028	20
x	3.90	4.06	.16	.032	6
xx	4.35	4.62	.27	.054	7
xxx	4.08	4.46	.38	.076	21

1/ Average of two sets of measurements taken at 6 and 18 inches from the bole of the tree.

trees to check the comparative growth of the healthy and mistletoe-infected limbs of the standing trees. From these data which are summarized in Table 15, it is apparent that the limbs had been infected at least 25 years prior to the time at which they were analyzed. The data presented in both tables show that, for the limbs examined, the rate of growth in diameter of limbs infected with mistletoe is greater than that of uninfected limbs. It is very probable that the increased diameter growth continues to a certain point beyond which there is a pronounced decrease in the rate of growth until the limb ultimately dies. This increased diameter growth is probably caused by the formation of an excessive amount of pathological parenchyma tissue as a result of the irritation of the cambium by the parasite. The softer parenchyma adjacent to the center of infection renders the infected wood somewhat weaker than the more highly-lignified tissues of normal uninfected wood. The presence of the mistletoe in the limb produces a stimulated growth of the host near the center of infection.

Eccentricities, especially hyponastic growth, are considerably more pronounced in limbs heavily infected with mistletoe than in healthy limbs. The formation of a large witches' broom produces an abnormally heavy load which must be borne by that portion of the limb nearest to the bole of the tree. This abnormal load produces

TABLE 13. - Comparison of the average diameter growth or accretion of 8 limbs on 4 felled western yellow pine trees, for a 25-year period, grouped according to degree of mistletoe infection.

Degree of Infection	Average Diameter[1] 1890	Average Diameter[1] 1895	Accretion 1890-95 Periodic Annual	Average Diameter[1] 1900	Accretion 1895-1900 Periodic Annual	Average Diameter[1] 1905	Accretion 1900-05 Periodic Annual	Average Diameter[1] 1910	Accretion 1905-10 Periodic Annual	Average Diameter[1] 1915	Accretion 1910-15 Periodic Annual	Basis
	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	No. of Limbs
0	1.68	1.84	.032	2.01	.034	2.21	.040	2.34	.026	2.46	.024	4
xxx	3.06	3.32	.052	3.68	.072	4.04	.072	4.34	.060	4.56	.044	4

[1] Average of two sets of measurements taken at 6 and 18 inches from the bole of the tree.

stresses which are sufficient to stimulate the formation of wood on the under side of the limbs through the deposition of food materials which renders it more able to withstand the compression below. The tension above is overcome by the development of a special tension tissue on the upper side of the limb.

The larger size of the limbs infected with mistletoe renders limbing and brush disposal in logging operations more difficult and consequently more expensive. The excessive secretion of resin which occurs in mistletoe-infected limbs also renders brush disposal somewhat more difficult and expensive.

Hypertrophy and Resin Flow:

Although mistletoe infection causes swellings on both branches and trunks, frequently the stem swellings soon become less noticeable as the tree grows and in many cases there are no pronounced swellings on the larger boles even when very old mistletoe infections are present; about the only means of detecting the infection being the presence of the mistletoe or the unusual roughness of the bark. On the other hand when infection occurs during the early life of the tree it frequently results in the formation of a burl which may attain very conspicuous proportions. The fusiform

swellings on both the stems and limbs resulting from mistletoe infections are centers where abnormal amounts of food materials are stored, which is evidently stimulated by the decided pathogenic tendencies of the mistletoe. Because of the soft spongy nature and the greater thickness of the inner bark of mistletoe-infected branches and stems the cortex is frequently gnawed from the lesions by rodents, especially porcupines and squirrels, thereby establishing a causal relationship between mistletoe infection and rodent injury.

As previously stated, there is more or less hypertrophy at the point of mistletoe infection on both limbs and stems. This hypertrophy is frequently accompanied by a copious flow of resin, which appears as small drops usually on the lower side of limbs which are heavily infected with mistletoe. A cross section through such a limb shows large areas of the sapwood thoroughly infiltrated with resin. This process of infiltration continues on many of the limbs until the fibbrovascular system is thoroughly clogged with resin, the limb girdled as far as receiving any food supply is concerned and is finally killed. This process is usually very gradual but nevertheless sure.

The resin flow from such mistletoe-infected limbs is not caused by insect punctures since a careful examination of the resin infiltrated areas fails to show any signs of insect injury. On many of the trees, heavily infected with mistletoe, resin cankers of varying sizes are found on the bole. These cankers are often directly associated with local mistletoe infection. These resin flows on the bole are usually indicative of a tree on the decline; in fact, trees with marked resin flow cankers usually die in a relatively short time. Such trees, therefore, should never be left for seed or protection purposes.

Effect on the Foliage.

Tables 14, 15, and 16 show the effects of the mistletoe on the foliage of the western yellow pine. The data included in Table 16 were obtained as follows:

Each tree crown was divided into three divisions, bottom, middle and top, including in each division about one-third of the total leaf surface. One hundred tufts from each section were selected at random and measured. The mean length of these 100 tufts was taken as the average length per tuft for that section; then 10 tufts of this average length were taken from each of

TABLE 14. - Comparison of the length of leaves of 103 western yellow pine trees, classified according to degree of mistletoe infection.

Degree of Infection	In Lower Portion of Crown			In Center Portion of Crown			In Upper Portion of Crown			Mean for Entire Crown			Basis
	Mean Min.	Mean Max.	Aver.	Mean Min.	Mean Max.	Aver.	Mean Min.	Mean Max.	Aver.	Mean Min.	Mean Max.	Aver.	
	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	No. of Trees
0	3.3	6.2	4.9	3.8	6.3	5.5	4.2	6.9	5.8	3.8	6.5	5.4	38
x	2.3	5.3	4.0	2.5	5.9	4.5	3.3	6.2	5.0	2.7	5.8	4.5	15
xx	2.1	5.3	3.8	2.5	5.4	4.1	2.9	5.7	4.6	2.5	5.5	4.2	18
xxx	2.1	5.1	3.6	2.4	5.1	4.0	2.7	5.1	4.0	2.4	5.1	3.9	32

TABLE 15. - Comparison of the length of leaf tufts of 97 western yellow pine trees, classified according to degree of mistletoe infection.

Degree of Infection	In Lower Portion of Crown			In Center Portion of Crown			In Upper Portion of Crown			Mean for Entire Crown			Basis
	Mean Min.	Mean Max.	Aver.	Mean Min.	Mean Max.	Aver.	Mean Min.	Mean Max.	Aver.	Mean Min.	Mean Max.	Aver.	
	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	No. of Trees
0	3.4	11.5	6.7	5.4	15.5	10.0	6.8	22.7	13.8	5.2	16.6	10.2	37
x	3.0	10.1	6.5	4.0	12.0	8.0	5.5	16.8	10.3	4.2	13.0	8.3	15
xx	2.4	8.2	4.9	2.3	9.1	5.2	3.4	11.1	7.3	2.7	9.4	5.8	15
xxx	2.3	8.1	4.5	2.6	8.6	5.0	2.4	8.5	4.8	2.4	8.4	4.8	30

TABLE 16.-Data showing the effects of mistletoe on the photosynthetic surface of western yellow pine.

Tree No.	Degree of infection	Age	Diameter breast high O.B.	Total height	Total volume	Crown Width	Crown Length	Crown class	Length of leaf tufts: Lower portion of crown Min.	Lower portion of crown Max.	Lower portion of crown Aver.	Lower portion of crown No. of tufts	Center of crown Min.	Center of crown Max.	Center of crown Aver.	Center of crown No. of tufts	Upper portion of crown Min.	Upper portion of crown Max.	Upper portion of crown Aver.	Upper portion of crown No. of tufts	Mean for entire crown Min.	Mean for entire crown Max.	Mean for entire crown Aver.
		Yrs.	Inches	Feet	Cu.ft.	Feet	Feet		Ins.	Ins.	Ins.	tufts	Ins.	Ins.	Ins.	tufts	Ins.	Ins.	Ins.	tufts	Ins.	Ins.	Ins.
103	XXX	80	7.5	20.0	2.50	10.0	15.5	X	0.5	7.0	3.2	81	1.0	8.0	3.8	329	1.0	12.0	5.7	254	0.8	9.0	4.2
104	0	79	14.5	42.0	19.00	17.0	32.0	X	1.0	11.3	5.3	2161	2.0	13.0	5.4	2390	2.0	18.0	8.0	1151	1.6	14.1	6.2
105	XXX	83	8.1	26.0	3.55	8.5	18.5	C	0.3	11.0	3.7	242	0.5	12.0	4.0	183	0.6	13.0	5.0	176	0.4	12.0	4.2
106	0	83	15.2	49.0	22.50	22.0	42.0	C	1.0	11.0	4.0	1522	1.5	17.0	6.7	1228	2.0	26.0	7.7	445	1.5	18.0	6.1
107	0	37	7.1	21.0	2.40	12.0	18.0	D	1.5	12.5	6.8	379	2.5	18.0	8.8	321	2.5	28.0	10.0	313	2.1	19.5	8.5

Tree No.	Total number of tufts in entire crown	Length of leaves: Lower portion of crown Mean Min.	Lower portion of crown Mean Max.	Lower portion of crown Mean Aver.	Lower portion of crown No. of leaves	Center of crown Mean Min.	Center of crown Mean Max.	Center of crown Mean Aver.	Center of crown No. of leaves	Upper portion of crown Mean Min.	Upper portion of crown Mean Max.	Upper portion of crown Mean Aver.	Upper portion of crown No. of leaves	Mean for entire crown Mean Min.	Mean for entire crown Mean Max.	Mean for entire crown Mean Aver.
		Ins.	Ins.	Ins.		Ins.	Ins.	Ins.		Ins.	Ins.	Ins.		Ins.	Ins.	Ins.
103	644	1.6	3.3	2.6	13,122	1.7	3.5	2.6	62,181	1.8	4.5	3.2	84,240	1.7	3.7	2.8
104	5,702	2.5	4.9	3.5	518,640	2.8	5.1	3.7	803,040	2.8	5.1	4.1	470,759	2.7	5.0	3.7
105	601	2.0	4.1	3.2	109,142	2.3	4.2	3.1	67,161	3.1	5.0	4.3	85,712	2.4	4.4	3.5
106	3,195	4.1	5.8	4.9	365,280	4.4	6.7	5.7	289,808	4.8	6.8	5.9	182,005	4.4	6.4	5.5
107	1,213	3.3	5.2	4.5	94,371	4.1	5.7	5.1	172,972	5.2	6.4	5.9	152,431	4.3	5.7	5.1

Tree No.	Total number of leaves in entire crown	Leaf surface: Lower portion of crown	Center portion of crown	Upper portion of crown	Entire crown	Ratio of leaf surfaces	Ratio of volumes
		sq. ins.	sq. ins.	sq. ins.	sq. ins.		
103	159,543	4,094.1	19,400.4	31,348.2	55,842.7	1.0	1.0
104	1,792,439	217,828.8	356,549.8	231,613.4	805,992.0	14.4	7.6
105	262,015	40,910.5	24,983.9	44,427.4	110,321.8	2.1	1.4
106	837,093	218,438.4	198,228.7	128,939.5	544,606.6	9.9	9.0
107	419,874	50,960.3	105,868.9	10,921.4	264,750.3	4.7	0.96

the three sections into which the crown had been divided. These 10 tufts, 30 in all for each tree, were put off and taken to the laboratory where the number of leaves per tuft, the length and width of each leaf were determined. The total number of tufts in the bottom, middle and top thirds were determined by actual count. The number of tufts thus obtained were multiplied by the average number of leaves found in the 10 tufts from each section. This gave the total number of leaves in each section. The sum of the leaves in the three sections gave the total number of leaves in any given tree crown. The average length and width of the leaves in the 10 tufts selected were used in determining the leaf surface for a given section of the crown and these in turn for finding the total leaf surface of a given tree. Table 16 shows that not only does the mistletoe shorten the length of both leaf tufts and leaves, but it also materially decreases the number of leaf tufts per tree for heavily infected trees when compared with healthy trees of the same age and site conditions. When two trees, one healthy and the other heavily mistletoed of the same size are compared, like Tree No. 103 and No. 107, it is seen that it has taken the mistletoe-infected tree more than twice the number of years to reach the same size as the healthy tree. The average ratio of

the leaf surface in square feet to the total value in cubic feet for the healthy trees given in Table 16 is 409.6 compared with 193.8 for the heavily infected trees, or over twice as great.

Trees heavily infected with mistletoe not only have considerably shorter leaves and leaf tufts than healthy trees but the leaves of mistletoe-infected trees are lighter in color than those of healthy trees, being a yellowish green, and an olive green on the healthy trees. Each heavy infection causes a localization and reduction of the photosynthetic or assimilatory leaf surface of the tree which in turn results in a marked decrease in the rate of growth.

Effect on Longevity of Host:

A number of permanent sample plots were established on the Coconino and Tusayan National Forests by the Fort Valley Experiment Station in 1909 to determine the rate of growth and decadence, the rate of establishment of natural reproduction, and the effect of various factors upon regeneration on cut-over areas. These plots were remeasured in 1914 and 1919. Some of the plots yielded valuable data on the amount of mistletoe infection and

the resulting mortality on cut-over areas.

On an area of 456 acres on the Tusayan National Forest about five miles from the Fort Valley Experiment Station, 2,636 black jacks or 34.9 per cent of the total number and 225 yellow pines or 34.8 per cent of the total number on the plot were infected with mistletoe in 1914. In 1919 2,535 black jacks or 28.8 per cent of the total number of trees 4 inches in diameter and over were infected with mistletoe. In many instances the infection was not sufficient to render the tree unhealthy but with the increase of infection many of the infected trees will pass through the various infection classes and soon die.

All of the trees which had died on the plots during the two 5-year periods were carefully examined and the cause of death noted. On the plot of 456 acres on the Tusayan National Forest 170 black jacks died from various causes during the first 5-year period or 2.2 per cent of the total number of black jacks living on the plot in 1909, while 21 yellow pines died during the 5 years which is 3.4 per cent of the total number of yellow pines living on the area. During the 5-year period from 1914 to 1919 127 black jacks died from mistletoe alone, or in conjunction with other agents

such as insects, porcupines, etc. On a plot of 135 acres located on the Coconino National Forest about 1-1/2 miles from the Fort Valley Experiment Station, 27 black jacks died during the first five years which is 1.1 per cent of the total number of black jacks living on the plot in 1909 while 26 yellow pines died during the first 5-year period or 1.8 per cent of the total number of yellow pines living on the area.

A digest of that part of the detailed records pertaining to mistletoe as a cause of the death of western yellow pine during the 5-year period from 1909 to 1914 is given in Table 17. The 456-acre plot on the Tusayan National Forest is located on an area which has sustained heavy losses from mistletoe, while the 135-acre plot on the Coconino is located on an area with only occasional heavy infections. A study of Table 17 indicates that of the 170 black jacks on the former plot which died during the 5-year period, 26.4 per cent were killed directly by mistletoe, 42.3 per cent by mistletoe combined with other agents, and only 31.3 per cent died from other causes, while only 4.8 per cent of the yellow pines were killed by mistletoe combined with bark beetles. On the 135-acre Coconino plot mistletoe infection alone resulted in the

TABLE 17. Classification of dead trees on permanent sample plots of 456 acres on the Tusayan and 135 acres on the Coconino National Forest showing the mortality of western yellow pine with mistletoe the direct cause or a contributing factor.

Cause of Death	Percent of Dead Trees 1909-1914 (Based on total number of trees which died during 5-year period)			
	456 acre plot, Tusayan National Forest		135 acre plot, Coconino National Forest	
	Black Jack	Yellow Pine	Black Jack	Yellow Pine
	Per cent	Per cent	Per cent	Per cent
Mistletoe	26.4		7.5	7.9
Mistletoe and Insects	35.0	4.8		20.2
Mistletoe and Porcupine	5.5			
Mistletoe and Suppression	1.4			
Mistletoe, Porcupine and Insects	.4			
All other causes	31.3	95.2	92.5	71.9
Total	100.0	100.0	100.0	100.0

death of 7.5 per cent of the total number of dead black jacks and 7.9 per cent of the total number of dead yellow pines, while mistletoe was a contributing factor toward the death of an additional 20.2 per cent of the yellow pines. During the five years 1.5 per cent of the total number of black jacks on the Tusayan plot in 1909 were killed by mistletoe alone or in conjunction with other agents, mainly insects. While this figure itself is not high it is alarming because the indications are that the death rate will increase from year to year. Although when this area was marked for cutting an effort was made to have all heavily-infected trees removed it is evident that mistletoe did not receive the attention which it deserved.

From the data presented above it is evident that the number of trees which die as a result of combined attacks of mistletoe and insects is considerable. Weir[4] has noted the same direct relation between mistletoe infection and insect infestation in the Northwest, especially with Dendroctonus valens. The origin of

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[4] Weir, James R. Mistletoe Injury to Conifers in the Northwest. U.S.Dept. Agri. Bulletin 360, 39 pp., 1916.

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numerous insect infestations has been traced to stands of western yellow pine heavily-infected with mistletoe. The main difference between mistletoe and insect injury is in the length of time required for the injury to become manifest. A sporadic insect infestation may develop rapidly and may kill a large number of trees in a relatively short time and it may even continue to increase until it is overcome and reduced to normal proportions through some natural agency. On the other hand the mistletoe develops comparatively slowly but continually and persistently. The bark beetles, when attracted by the resinous exudations of the mistletoe-infected trees, may materially hasten the death of the host which already has been weakened by the parasitic mistletoe. Trees dead or dying from mistletoe infection have been found infected with species of secondary bark beetles and borers, such a Ips, Pityophthorus, Chrysobothris, and Melanophila.

Three black jack saplings under four inches in diameter breast high on one of the intensive mistletoe study plots died during the 5-year period as a direct result of mistletoe infection. Five yellow pines, on the same area were also killed by mistletoe during the

same period. Many of the other trees on the sample plots, although not dead at the last examination were small and stunted. They were making an almost inappreciable growth and were very unhealthy in appearance. Some of these, which are apparently unable to endure the parasitism of the mistletoe combined with a rather adverse climate, will undoubtedly succumb before the next remeasurement of the plots at the end of the next period of five years. Practically all of the trees which are heavily infected with mistletoe are ultimately doomed since it is only a question of the length of time which they can withstand the insidious action of the parasite.

EFFECT OF MISTLETOE ON MERCHANTABILITY OF TIMBER

Although the mistletoe injury to the host results less in the depreciation of the lumber than in the impairment of the vital physiological functions of the host, there is nevertheless an appreciable effect on the quality of the lumber. The accelerated growth of mistletoe-infected limbs, as shown in Tables 12 and 13, results in larger limbs which produce knots of a larger size in the lumber that is sawed from

mistletoe-infected trees. The number of knots is also increased due to the greater number of secondary branches and twigs in stem infections. The increased size and number of the knots may, in many cases, be sufficient to lower materially the grade of the lumber.

Mistletoe infection produces a curly or abnormally-grained and a weaker wood. Wood invaded by the thread-like sinkers of the mistletoe is spongy. The wood is frequently discolored and pitchy which is due in most cases to the resinous flow or bleeding of the trees as a result of the parasitism. The presence of mistletoe burls renders a tree more susceptible to wind breakage and in addition may ruin a portion or all of a saw log. A seedling or sapling whose stem is infected with mistletoe will seldom develop a bole large enough to yield any considerable quantity of lumber and very rarely, if at all, lumber of a high grade. It is therefore evident that, aside from the physcologically injurious effect of the mistletoe, it also introduces a cull factor in that mistletoe-infected trees produce a poorer grade of lumber than healthy trees.

EFFECT OF MISTLETOE ON SEED PRODUCTION OF HOST

Pearson[5] has shown, as a result of seed collected in 1909, that seed from mistletoe-infected black jacks gave a germination of 17 per cent below that of healthy black jacks, which had a final germination of 78 per cent. The present study led to the conclusion that, although the mistletoe may stimulate growth in that portion of the host adjacent to the parasite, causing the abnormal development of certain limbs and branches into witches-brooms, the excess of carbohydrates produced by the additional foliage of the mistletoe-stimulated branches is consumed by the parasite thereby reducing the amount available for the seeds. The final effect upon the host in all cases is insidious, slowly depriving the tree of its vitality instead of causing injuries in the nature of a shock, as in the case of burns and other mechanical injuries.

In order to check further this theory additional seed collections were made by the Fort Valley Experiment

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[5] Pearson, G. A. The influence of age and condition of the tree upon seed production in western yellow pine. U.S. Dept. of Agri., Forest Service Cir.196, pp.11. 1912.

Station in 1913 and 1915 from mistletoe-infected and healthy western yellow pines. Aside from the difference in degree of mistletoe infection the trees were otherwise normal and very similar in age and crown development and were not suffering from any other injurious factor. The cones from each tree were kept separate and the seed extractions and germination tests were conducted separately for each tree. Five hundred seeds from each lot were germinated in sand in the greenhouse at a temperature ranging from 40 to 90 degrees F. with a mean daily temperature of approximately 65 degrees. Daily counts were made during the progress of the germination tests, which continued for approximately 50 days. The pertinent data on the seed production of 64 felled western yellow pine trees for the 1913 and 1915 collections is classified in Table 18 according to the degree of mistletoe infection. The best criterion by which to judge the relative seed production is believed to be the reproductive value of each tree or the total number of viable seeds produced per tree which represents a convenient summation of the fundamental variables of seed production. This is obtained by multiplying the yield per tree in pounds of clean

TABLE 18. - Data on the seed production of 64 felled western yellow pine trees classified according to degree of mistletoe infection.

Degree of Infection	Final Germination	Clean seeds per pound	Yield per tree		Reproductive value per tree	Basis
			Cones	Clean Seed		
	Per cent	Number	Bushels	Pounds	No. of viable seeds	No. of trees
			1918 Collection			
0	82.8	14,473	0.8	1.08	12,942	43
x	84.1	14,385	1.0	1.10	13,292	2
xx	81.7	13,514	0.5	0.45	4,895	2
xxx	77.0	14,475	0.3	0.31	3,455	2
Mean of x,xx and xxx	80.9	14,058	0.6	0.62	7,052	6
			1915 Collection			
0	52.8	12,156	1.1	0.87	5,626	11
Mean of x,xx and xxx	47.1	14,170	0.9	0.53	2,202	4

seed by the number of clean seeds per pound and in turn multiplying the product by the final germination per cent. It will be noted that, with the exception of the lightly-infected class upon which the mistletoe appears to have a slight stimulating effect, there is a decrease in the percentage of germination, the yield of cones, and clean seed per tree and consequently a marked decrease in the reproductive value per tree with an increase in the amount of mistletoe infection. The reproductive value of the trees in the intermediate infection class is about 40 per cent of that of the healthy class, while the reproductive value of the trees in the heavily-infected class falls to only about 25 per cent of that of the healthy class. This is really not at all surprising when the effects of the parasitism are fully understood. The data for the mistletoe-infected classes of felled trees reported in Table 18 is meager because of the difficulty experienced in securing seed from mistletoe-infected trees, owing to the sterility of the cones and their failure to develop. In fact a diligent search was made for heavily-mistletoed trees which were bearing seed, but very few were found.

The extent and condition of the seed crop on the standing trees on the permanent sample plots referred to above, was under observation from 1912 to 1916 in order to secure additional data on the effect of mistletoe infection on the amount and periodicity of seed production. The 1912 seed crop was rather light, only a few of the trees bore any large quantity of cones. In 1913 there was an average crop, with practically none in 1914, while the 1915 seed crop was somewhat below the average. The records of the 1912 and 1915 seed crops for 177 of the living western yellow pines are classified in Table 19 by degree of mistletoe infection and amount of the seed crop. The seed crops were arbitrarily classified by the same observer as heavy, good, medium, light or none. An analysis of the data shows that the amount of seed production varies inversely with the degree of mistletoe infection; as the degree of mistletoe infection increases the amount of seed produced decreases until very little, if any, seed is produced by heavily-infected trees. These results are further substantiated by observations of the writers covering a period of approximately 10 years. Trees heavily-infected with mistletoe produce small amounts of seed

TABLE 19. - Record of 1912 and 1915 seed crops for 90 standing western yellow pine trees classified by degree of mistletoe infection and amount of seed crop.

Degree of Infection	Amount of seed crop										Total Basis
	Heavy		Good		Medium		Light		None		
	No. of trees	Per cent	No. of trees	Per cent	No. of trees	Per cent	No. of trees	Per cent	No. of trees	Per cent	No. of trees
				1912 Seed Crop							
0	0	0	0	0	2	5.3	9	23.7	27	71.0	38
x	1	7.7	0	0	1	7.7	4	30.8	7	53.8	13
xx	0	0	0	0	0	0	5	25.0	15	75.0	20
xxx	0	0	0	0	0	0	0	0	16	100.0	16
				1915 Seed Crop							
0	0	0	1	2.8	2	5.5	15	41.7	18	50.0	36
x	0	0	0	0	2	14.3	5	35.7	7	50.0	14
xx	0	0	0	0	0	0	4	18.2	18	81.8	22
xxx	0	0	0	0	0	0	0	0	18	100.0	18

at such times as there are generally heavy seed crops, and at other times practically none. The few cones that may occasionally be found on trees heavily infected with mistletoe are very often aborted, and are frequently infected with a cone insect (Conophthorus ponderosae)[6].

[6] Material determined by Office of Forest Insect Investigations, Bureau of Entomology, U.S.Dept. of Agri.

A similar deterrent effect of mistletoe on the seed production of Douglas fir, western larch, and lodgepole pine has also been found by Weir[7] to obtain in the Northwest where seed collected from very old

[7] Weir, James R. Mistletoe Injury to Conifers in the Northwest. U.S.Dept. of Agri. Bul. 360, 39 pp., 1916.

mistletoe brooms showed a germination on an average of 10 per cent below that of seed taken from uninfected branches of the same trees. Munns[8] reports that Jeffrey

[8] Munns, E. N. Effect of Fertilization on the Seed of Jeffrey Pine. Plant World 22: 138-144, 1919.

pine trees infected with mistletoe had half as many more seed to the pound as were found in the cones on thrifty

trees, but the germination was 20 per cent lower and the seedlings produced were not as vigorous. It seems very improbable that moderate or heavy mistletoe infection would ever act as a stimulus upon seed production, because its slow insidious action makes constantly greater demands upon the vitality of its host. Therefore trees moderately or heavily infected with mistletoe are of little or no value for the purpose of seed production.

Foresters recognize the fundamental fact in silviculture, as established by European studies,[9] that variations in the individual characteristics of

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9 Engler, Arnold. Einfluss der Provenienz des Samens auf die Eigenschaften der forstlichen Holzgewache. Mitteilungen der Schweizerchen Centralanstalt fur das forstliche Versuchswesen, Zurich, 1905, B. 8, 81-236; 1913, B. 10, S. 1-386.

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the parent trees are hereditarily transmitted through the seed. The extent to which the origin of the seed influences such characteristics as the resistance or immunity to disease, the rate of growth, and the growth-form of the regenerated forest is of vital importance in the rational practice of scientific forestry.

The experiments of Zederbauer[10] indicate that trees

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10 Zederbauer, E. Centralblatt fur das gesamte Forstwesen, 1912, s. 201.

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grown from seed collected from intermediate, suppressed and weakened trees are less resistant to disease than trees grown from seed produced by dominant and vigorous trees. The hereditary characters of the species are not changed materially during one rotation. Several generations are necessary to show the true effects of those characteristics of the parent tree which may be transmitted through the seed, such as an unusual divergence from the typical silvical characteristics of the species. A clearer conception of the latent possibilities of disease resistance and immunity of a species obtained through tree breeding is of vast importance in the silvicultural improvement and management of the forest. The hereditary influence of the parents upon the offspring is a well recognized factor in genetics. This factor is doubly important in forestry, not only in the collection of seed for artificial regeneration, but also in the selection of seed trees to provide for the natural reproduction of cut-over forests. In timber sale practice only thrifty seed trees should be left and all diseased and suppressed trees should be removed in order to improve the condition of the forests of the future.

SILVICULTURAL ASPECT OF MISTLETOE INFECTION

The large amount of damage which is being done by the yellow pine mistletoe has been most strikingly shown during the progress of this study. Mistletoe presents one of the most serious problems in the silvicultural management of the forests of the Southwest. The destruction from disease promises to approach or even surpass the losses from fire, now that the development and perfection of fire protection on the National Forests of the Southwest has reduced the fire hazard to a relatively small amount. It is inevitable that the forests will continually sustain certain comparatively small losses from lightning fires and a certain amount of unpreventable windfall. On the other hand the greater part of the loss due to mistletoe injury can be prevented and ultimately after the lapse of several rotations these losses should be reduced to a very small amount. The mistletoe may be slow in effecting its injury, but it is unquestionably certain.

A brief discussion of some of the salient objects of silviculture is deemed essential to a complete understanding of the significance of any methods of control which may be promulgated. The chief fundamentals of silviculture to be applied in the regeneration of western yellow pine stands are to maintain

the continuity of the forest and to increase its productivity. The pathological aspect should be considered fully in formulating a silvicultural management policy for any forest. It is evident therefore that the chief object of forest regulation is the continuous maximum production of sound healthy timber. A number of basic considerations must be taken into account under any rational method of cutting, among which may be mentioned, the silvics of the species, the fire hazard and liability, exploitation and economic conditions, and the removal of the decadent, unhealthy and overmature timber as rapidly as possible to avoid waste through decay. All defective, diseased and suppressed trees should be marked for cutting unless needed as fire insurance or seed trees. However, a defective or diseased tree should not be left standing if it is evident that it will not live until the next cutting unless it is absolutely required for silivicultrual purposes. When it becomes necessary to reserve trees among the larger diameter classes, thrifty healthy trees of good form should be selected, since the condition of the resultant progeny is influenced by heredity as well as by soil and climate. The tendency toward increased forest productivity will be realized if in the application of the above principles, the forester will

strive to increase the merchantability and eliminate the deterioration of merchantable material. It is thus evident that the marking on each individual acre must be varied to meet the silvicultural requirements of the forest. The importance of careful, intelligent marking on timber sale areas cannot be overestimated since this, the most important of silvicultural activities, is the practicable means by which rational silvicultural management is actually secured.

Meinecke[11] has suggested the establishment of

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11 Meinecke, E. P. Forest Pathology in Forest Regulation, U. S. Dept. of Agri. Bul. 275, p.59. 1916.

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pathological rotations for species of economic importance which are subject to serious diseases. A pathological rotation may be defined as the period during which the timber crop may grow and be subject to exploitation at a profit, but beyond which rapid deterioration is imminent and the product will be marketed at a great reduction in value. The pathological rotation is, therefore, rather a limiting factor and, with regard to heartwood destroying fungi entering the heartwood through open wounds, is based upon the age of decline or the age at which even unwounded

trees become subject to heavy infection because they are unable to throw off or to hold the growth of the parasite in check. From the discussion in the earlier part of this paper it will be seen that the mistletoe may kill small seedlings only a few years old as well as veteran western yellow pines two or three hundred years old. It is therefore evident that it would not be practicable to attempt to establish a pathological rotation for mistletoe-infected western yellow pine.

CONTROL OF MISTLETOE

It is evident from the preceding pages that the mistletoe is a serious and widely distributed enemy of the western yellow pine forests of the Southwest, and presents a serious silvicultural problem in this region. Any method of control which may be promulgated must be adapted to existing conditions. As in the case of other diseases prevention is the basis for the control of mistletoe. The protection of healthy stands of timber from disease is accomplished mainly by removing the source of infection.

Mistletoe is more susceptible to control measures than many fungi. Mistletoe infection is confined to the aerial parts of the host while fungi may infect the subterranean as well as the aerial parts.

The seeds of the mistletoe, which are much larger than the microscopic spores of fungi are not subject to as wide dissemination as the latter. Mistletoe is killed with the death of its host whereas certain fungi may remain alive for an indefinite period following the death of their hosts.

As has been indicated in the preceding pages, it is evident that mistletoe develops rapidly after cutting since many of the trees left standing on the permanent sample plots were killed by mistletoe during the five years following the logging operation and many more, although still alive, will die in the course of a relatively few years. Mistletoe was found to be directly or indirectly responsible for by far the greater number of deaths of western yellow pine in which it appears as only one of several contributing causes.

All of the facts at hand indicate that the cutting of mistletoe-infected trees is the only practicable method of control although it is doubtful whether in certain cases the removal of lightly-infected trees would be warranted because of silvicultural reasons.

Since mistletoe appears to spread more rapidly and to grow faster on lightly-infected trees as a result of increased wind and light following cutting through providing more favorable conditions for the optimimum development of the parasite, every effort should be made

to entirely free the stand of mistletoe infection. The increased activity of the mistletoe following the opening of the stand militates against leaving for a future cutting operation any but lightly infected trees, the infection of which is confined to the lower portion of the crown. Old and heavily-infected trees should be cut for two reasons; (1) to improve the hygienic condition of the forests of the future through the removal of the mistletoe, and (2) to secure the maximum realization on a rapidly diminishing growing stock or forest capital. Since the future productivity of the forest depends to a great extent upon the proper choice of seed trees or of the seed itself in the case of artificial regeneration, those trees used for reproductive purposes should be sound, healthy, and of an intermediate age class.

As heavy a stand of healthy trees as possible should be left in order to compensate for the removal of diseased trees, and to maintain better forest conditions, reduce wind damage and to insure a denser stand of reproduction. Exceptional care should be taken to leave every healthy black jack which is free from infection. Wherever possible, trees should be freed from light infections by cutting off lower branches within reach. Transition trees and vigorous yellow pines, suitable for seed trees, if healthy, should be

left in greater numbers to take the place of diseased black jacks removed, to maintain better forest conditions and to furnish abundant seed for the restoration of the stand. Small heavily-infected black jacks should be marked wherever it is possible to have them cut under the sanitation clause of the timber sale contract, or where there is a market for small material, such as stulls, mine props, ties, poles, posts and pickets. Areas of reproduction infected with mistletoe should be destroyed.

The best opportunity for freeing the forest of mistletoe is presented at the time of cutting. Forest officers in charge of marking on mistletoe-infected timber sale areas should study carefully the possibilities of increasing the number of healthy trees in the remaining stand. The pruning of infected limbs from small trees at the time of marking presents a practical means of eliminating light limb infections and at the same time increasing the number of healthy trees. Occasionally there are trees in a stand that are lightly infected on a low branch within reach of the ground. Mistletoe-infected reproduction and young timber below merchantable size should also be freed from the disease either through cutting the seedlings and saplings or by lopping off the infected branches. Such measures may be impractical except on timber sale areas and in some

cases the extra labor and expense involved may prove prohibitive. Additional help may be necessary in marking heavily-infected areas in order to free them of mistletoe. Otherwise they will remain as centers of infection and will likely produce little or no healthy timber, thus being practically eliminated as productive forest areas for all time.

The problem of the control of mistletoe, however, assumes two quite different aspects depending upon the degree of infection on a given area. On areas of light to moderate infection where the injury is not very serious the marking rules should call for the removal of all mistletoe-infected trees possible without breaking up the continuity of the stand of materially interfering with the silvicultural system of management adopted for the area. Here special emphasis should be laid upon the greater need of leaving all healthy trees possible even if they belong to the "yellow pine" class, in order to insure as good a condition of the forest cover and seed production as possible. Lightly infected areas should be marked in such a manner that, with supplemental pruning at the time of marking, the stand would be practically free of infection. Silvicultural systems of regeneration should be subordinated to the eradication of the mistletoe from the stand. All heavily infected trees should

be cut regardless of the stand after cutting. Moderately infected trees should always be marked for cutting except where there are no other trees available to leave as seed trees. Mistletoe can not in all cases be eliminated in one cutting without too great a sacrifice of silvicultural requirements. Moderately infected trees should not be left for seed on lightly infected areas if healthy trees are available within 100 yards. This, however, applies to large areas rather than to small openings or small areas which have a chance to seed in from surrounding trees and where infection might be removed completely without opening the forest too extensively. Moderately infected trees should be left for soil protection purposes only on the most adverse sites, where their need for this purpose is clearly evident. Lightly infected black jacks and transition trees on areas bearing no advance reproduction, should not be cut when otherwise thrifty and sound except where thinnings are desirable to obtain increased growth or where reproduction is established. Such thinnings, however, may be somewhat heavier than in uninfected stands, but in lightly infected black jack stands where reproduction is not established, vigorously growing and thrifty trees should not be radically sacrificed. Lightly infected yellow pines should be left when uninfected trees or

lightly infected black jacks are not available for seed and protection. On areas adequately stocked with advance reproduction, all infected trees should be cut.

Areas of heavy infection on which the injury from mistletoe is alarmingly serious should receive special attention and should be treated from the standpoint of the sanitation of the forest. Areas where the entire stand is too heavily infected to permit carrying out sanitation measures without material interference with the silvicultural requirements of the forest should be marked for clear cutting. In practice such a condition will probably seldom be encountered. The largest possible number of small trees infected with mistletoe should be utilized. Areas of unmerchantable reproduction infected with mistletoe should be freed of the disease either through cutting the diseased seedlings and saplings or by pruning off infected branches. In certain cases it would be fully as desirable for the owner of the forest to devote special funds for mistletoe control projects, as is done in the case of serious insect infestations. While the areas infected with mistletoe to such an extent that diseased trees must be left, or the stand practically clear cut, are not extensive, areas will probably be found on which forest planting to fill in blank growing spaces will be desirable following operations approaching a clear

cutting under a mistletoe-control project. It may also be advisable from the standpoint of economy to clear cut and plant certain limited areas of heavy infection. A definite policy of mistletoe control should be adopted for mistletoe-infected areas to be cut over by timber sales. Necessary funds should be provided to complete the cleaning of the areas after the operator has removed all of the diseased trees which he can be required to take under the agreement.

The areas of mistletoe infection should be located and mapped as a prerequisite to an efficient control campaign. The degree of injury and the amount of infection should also be recorded. Weir[12] has suggested that this could easily be done by timber survey parties in connection with their regular mapping and cruising work. Such tangible records of mistletoe infections would be invaluable to Forest officers in showing just where diseased stands are located in order that an attempt be made to exploit stands of seriously diseased timber as rapidly as possible.

The advent of a large commercial timber-sale operation should not be awaited before undertaking mistletoe control work. Small ranger sales and even the issuance of free use permits should materially

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12 Weir, James, R. Some Suggestions on the Control of Mistletoe in the National Forests of the Northwest. Forestry Quarterly 14: 567-577, 1916.

assist in the reduction of severe infections. Although in many instances the large lumbering operation is more economical than the small one, the latter can render a definite service in improving the hygenic condition of the forest through removing more or less isolated infections which are too small to be exploited in a large operation. The products of the small operation are not marketed in as highly-finished or specialized form as are many of the products of the large operation. In the case of a small lumbering operation mistletoe-infected trees will, in almost every case, be as well adapted to the desired uses as the products of healthy trees.

Forests in the vicinity of nurseries and planting areas should present unusually healthy conditions. It should be remembered that healthy trees can not be grown in an insanitary environment. Therefore, all mistletoe infection in the vicinity of forest nurseries and planting areas should be removed.

When a proposed timber-sale area contains a considerable amount of mistletoe, a special mistletoe sanitation clause should be inserted in the contract, containing the stipulation that all heavily infected trees, whether merchantable or unmerchantable, and certain other moderately infected trees will be marked for cutting. If the amount of unmerchantable infected

timber were sufficient to materially affect the stumpage prices, this factor should be fully taken into consideration and due allowance made for it in the stumpage appraisal.

In control work on those areas where both mistletoe and insects are present it would be advisable to combine the eradication of both pests where the commercial value of the stand would justify such measures. Infections of secondary bark borers have occasionally been found and reported with or immediately following mistletoe infection.[13] It is believed that certain of these insects even show a slight preference for trees attacked by mistletoe. The attack of trees weakened by the mistletoe often hastens their death or in the case of dead trees the work of the borers hastens deterioration. The control of such combined infections and infestations by eliminating the weakened trees would tend to control both mistletoe and insects and thus further the cause of the ultimate ideal - a productive, thrifty and healthy forest.

The western yellow pine mistletoe probably has few natural enemies which can contribute toward its

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[13] Hopping, Ralph. Insect Infestation in Relation to Injury Fungi, and Mistletoe. Manuscript Report. Feb. 24, 1915.

control. During the course of the studies reported in the preceding pages a spittle insect (Clastoptera obtusa)[14] was very frequently found within masses of spittle on the mistletoe plants. The work of the insect in controlling the mistletoe is probably of little practical importance. However, since the insect subsists on the juices of the mistletoe it must tend to weaken the mistletoe to a certain extent especially in cases of severe infestations.

Through a proper realization and appreciation of the necessity for, and the adoption of adequate control measures on all cutting areas where the amount of mistletoe infection is relatively great a very good beginning can be made toward the eradication of the pest through the more or less gradual process of elimination.

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14 Determined by Mr. E. H. Gibson, Scientific Assistant, Bureau of Etomology, U. S. Dept. of Agriculture.

SUMMARY

Western yellow pine is subject to severe injury by mistletoe, (Razoumofskya cryptopoda). The injury to the forest caused by the insidious and destructive action of this pest results in serious losses of western yellow pine and presents one of the most important silvicultural problems in the Southwest.

Mistletoe infection causes a marked decrease in the rate of growth of the host, which continues until ultimately the virulent parasite causes the death of the tree. The rate of decrease varies directly with the degree of infection from a very marked falling off in the current growth of heavily-infected trees to a very slight or no decrease in the growth of lightly-infected trees. Many trees are killed annually by this pest alone or in conjunction with other causes such as insect infestations or porcupine injury.

The decrease in the rate of diameter and height growth and consequently the current increment of trees infected with mistletoe, is accompanied by a reduction of the leaf surface of the host.

Trees of all age classes are subject to mistletoe infection provided the seeds of the parasite fall on parts of the tree which are not protected by the suberized cortex. Young seedlings and saplings usually die comparatively soon after becoming severely infected while older trees may remain alive for a much longer time.

The quantity and quality of the seed produced by trees infected with mistletoe is below that of normal healthy trees. Heavily-infected trees are practically worthless for seed production and should not be left as

seed or fire insurance trees for the purpose of regenerating the forest.

The most practical method of controlling mistletoe is to remove the infected trees while cutting operations are in progress. All heavily-infected trees should be marked for cutting. On areas of light to moderate infection the marking rules should require the removal of all mistletoe-infected trees possible without breaking up the continuity of the stand or materially interfering with the silvicultural requirements of the forest. Exceptional care should be taken to leave as heavy a stand of healthy trees as possible in order to compensate for the removal of diseased trees and to maintain better forest conditions. Moderately infected trees should be marked for cutting except where others are not available for seed trees.

Areas on which the entire stand is too heavily infected with mistletoe to permit adequate sanitation measures without very material interference with the silvicultural requirements of the forest should be marked for clear cutting under a mistletoe control project. Although in actual practice such a condition will seldom be encountered, relatively small areas will probably be found on which forest planting may be desirable.

When proposed timber-sale areas contain a great amount of mistletoe a sanitation clause should be inserted in

in the timber-sale contract requiring the cutting of all heavily-infected trees, whether merchantable or unmerchantable, and certain other moderately infected trees which may be marked.